University of Stavanger

Faculty of Science and Technology

MASTER'S THESIS

Study program/ Specialization: Offshore technology / Industrial asset management	Spring semester, 2011 Restricted access
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Title of thesis: Development of a work process for condition management of topside static mechanical equipment	
Credits (ECTS): 30	
Key words: Risk-Based Inspection Condition monitoring Condition management	Pages: 58 + enclosure: 3 Stavanger, 03.06.2011 Date/year

ABSTRACT

Degradation and fatigue of static equipment is common in the offshore industry. The combination of saltwater, temperature, and humidity can significantly reduce the integrity of static process equipment, and thereby increase the possibility of failure. Condition monitoring and inspection of oil and gas production facilities are regularly performed to maximize availability, but the vast amount of data and imperfect results may be difficult to interpret.

Inspections on static process equipment are usually planned and executed based on risk-based principles, where risk is defined as a combination of consequence of failure (CoF) and probability of failure (PoF). This technique is called Risk-Based Inspection (RBI) planning. The inspection plans are based on the risk-evaluation and degradation rate calculated using base parameter values (e.g. flow rate, production, temperature, pressure). However, the values are static which gives a narrow view of the process since fluctuations of parameters are common at such production facilities.

Condition monitoring (CM) is a technique where the process condition is monitored either continuously or periodically. This technique monitors process parameters (e.g. temperature, pressure, flow rate, etc.) and feeds the user/onshore engineer with data regarding the equipment. The data collected may then be used to ascertain the possible rate of degradation mechanisms, which in turn can be used to calculate PoF, CoF and eventually risk.

A condition management system integrates the condition monitoring and risk-based inspection. The collection of live process parameters is integrated dynamically with the RBI analysis, optimizing the decision-making for inspection and maintenance planning of topside static mechanical equipment.

This thesis presents a work process for how a condition management system could be designed. It will give guidance on how information and data should be assessed and integrated to give the user/onshore engineer useful and effective support.

ACKNOWLEDGMENT

This thesis is submitted as a partial fulfilment of the requirements for the degree of Master of Science and Technology at the University of Stavanger (UiS), Norway, in the study programme of Offshore Technology, within the specialization of industrial asset management.

The work was carried out at "Det Norske Veritas" (DNV) Stavanger office, in the period between January and June 2011.

I would like to give my special thanks to my supervisors, Professor Tore Markeset (UiS), Dr Maneesh Singh, and Mr Kjetil Eikeland for their guidance, support and inspiration.

I am also very grateful to Mr Frode Wiggen at DNV for giving me the opportunity to study this topic. I also appreciate the support and inclusive environment from everyone at DNV Stavanger office, especially the other master students: Henning Rebnord and Christine Berner.

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CHAPTER 1
Introduction

1.1 Background

Inspections and maintenance are today planned by using static data which is gathered on intervals with respect to the equipment's risk category. This works to some degree, but it is not effective with respect to cost or manpower, and unforeseen fluctuations in the process data can occur. Process data on factors like flow, temperature and pressure has a big impact on the degradation mechanisms of materials. For the RBI analysis to be effective, it is important that parameters in the inspection plan are updated so the inspections are executed at the "right time", since this would increase safety and decrease cost.

As of today, limited work has been carried out to show how to integrate condition monitoring of process parameters and Risk-Based Inspection (RBI), even though the advantages are obvious. Thus it is important to develop a work process giving guidance on how this could be done, and also showing important factors as well as the pitfalls one should avoid. The work process developed in this thesis should be easily adapted to existing facilities to reduce the cost of implementation.

This thesis presents the details of a proposed work process for integrating condition monitoring and RBI to develop an effective condition management system.

1.2 Aim of the thesis

The aim of the project is to develop a work process for condition management by integrating condition monitoring of process parameters and RBI. This thesis will also give experience in creating work processes as well as an introduction to RBI and condition monitoring.

The proposed approach should allow for the proper use of available data, obtained through condition monitoring, by connecting it to the RBI analysis. The procedure should thus support optimized decision-making for the inspection and maintenance of topside static mechanical equipment.

1.3 Scope

The scope of this thesis is to develop a work process for how to implement an effective condition management system which should be easily adapted to existing facilities, avoiding the costs of modifications.

1.4 Limitations

The limitation for this thesis was to keep it on a general level and not to go too deeply into how everything works, but instead to give a clear picture of the work process itself. Other limitations were:

- The thesis will be based on a detailed literature study combining the best of condition monitoring and RBI techniques.
- The thesis will focus on topside static mechanical equipment.
- The thesis will in general focus on how the continuous monitored data can be integrated with periodic data, and support inspection planning and execution.

1.5 Thesis approach

This thesis is based on a detailed literature study and an existing framework for condition management. The thesis is done qualitatively through using available information concerning condition monitoring and RBI combined with the student's own knowledge. Standards and recommended practices are also used to make sure the procedure is up-to-date on laws and regulations.

The second chapter will give general information about what condition management is based on. This will give the reader a fundament for understanding the main part of the thesis.

The third chapter is the thesis itself, in which a work process for implementing condition monitoring is presented. This chapter is divided into sub-chapters, each of which represents one step in the condition management system. Each step is organized so the preceding step is directly connected to the one that follows. However, since it is a complex system, there are also connections back and forth between chapters to give the reader a full picture of the complete system.

Chapter four discusses challenges in the thesis and how these were solved, while chapter five presents the conclusion of this thesis.

1.6 Abbreviations

CBM – Condition Based Maintenance
CM – Condition Monitoring
CoF – Consequence of Failure
CUI – Corrosion under Insulation
DCS – Distributed Control System
DNV – Det Norske Veritas
ESCC – External Stress Corrosion Cracking
FMECA –Failure Mode, Effects, and Criticality Analysis
FORM – First Order Reliability Method
GUI – Graphic User Interface
HIC – Hydrogen Induced Cracking

ICT – Information and Communication Technology
I/O – Input/Output
MC – Monte Carlo
MIC - Microbiologically Induced Corrosion
NDT – Non Destructive Testing
OE – Onshore Engineer
OLE – Object Linking and Embedding
OPC – OLE for Process Control
PLC – Programmable Logic Controller
PLL – Potential Loss of Life
POB – Personnel on Board
PoF – Probability of Failure
P&ID – Piping and Instrument Diagram
RBI – Risk-Based Inspection
RDBMS – Relation Data Base Management System
SSC – Sulphide Stress Cracking

CHAPTER 2
Literature overview

2.1 Introduction

Planning inspections and maintenance is a focus area for offshore industries because of costs and safety issues. Performing inspections at the “right time” would decrease cost and increase safety, through avoiding unnecessary inspections. This is a predictive approach, where the equipment’s condition shows when inspections and maintenance should be carried out. The whole idea is to find the optimal time-to-inspect with respect to cost and safety.

In this chapter, the two methods that are going to be integrated will be presented: RBI and condition monitoring. These two methods will be presented respectively since they are a big part of this thesis. This general information is required to understand the work process for condition management (ref. Chapter 3). The two methods are presented based on a literature overview.

2.2 Risk-based inspection analysis

Risk-based inspection (RBI) is a risk-dependent planning method for inspections of static equipment. It is a risk-based approach, where the time-to-inspect will depend on the risk category for every single item of equipment – which is obtained by a combination of probability of failure (PoF) and consequence of failure (CoF) (DNV, 2009).

The RBI analysis can be performed in three ways: qualitatively, quantitatively or semi-quantitatively/qualitatively. The quantitative RBI analysis is built on calculations, and therefore it requires large amounts of correct input data. This makes the results from the analysis accurate, but it is hard to collect the required amount of data and assure that it is correct. The qualitative method is built on subjective values, often made by experts, e.g. inspection, material, and structural engineers. The results will therefore depend on the knowledge and experience of these experts, which might be deficient. The most common way of using RBI combines these two. The available data (quantitative method) and expert knowledge (qualitative method) are integrated, thus giving a fundament for further decision-making. The deliverables of an RBI assessment are given in Figure 2.1.

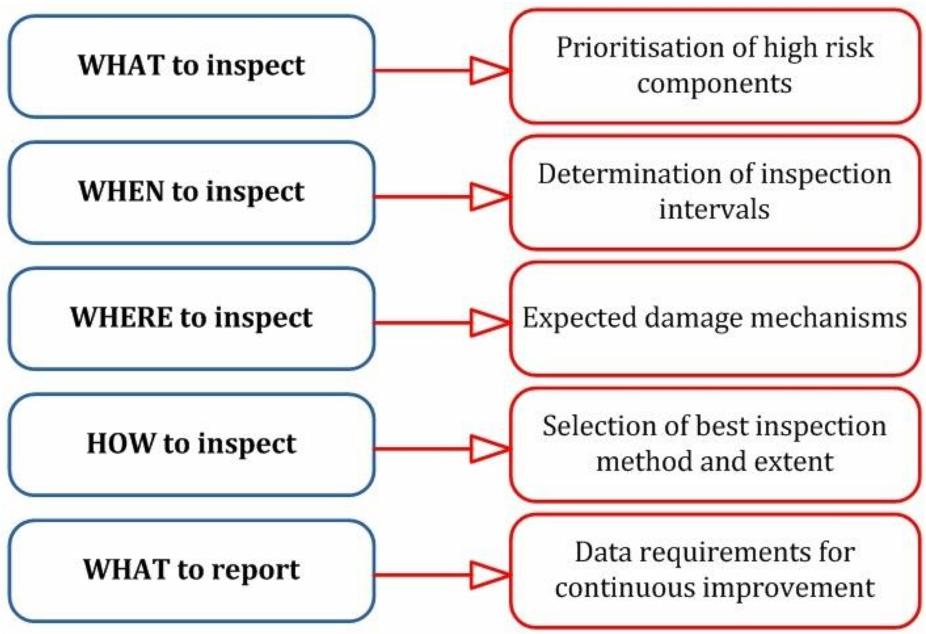

Figure 2.1 Deliverables of a RBI assessment (Adapted from DNV presentation 1, 2010)

The RBI assessment is a time-consuming method since production facilities often consist of a large number of items of equipment. Thus, a thorough work process has been developed for performing a RBI assessment (DNV, 2009). Figure 2.2 shows the inspection management loop in which RBI analysis is incorporated.

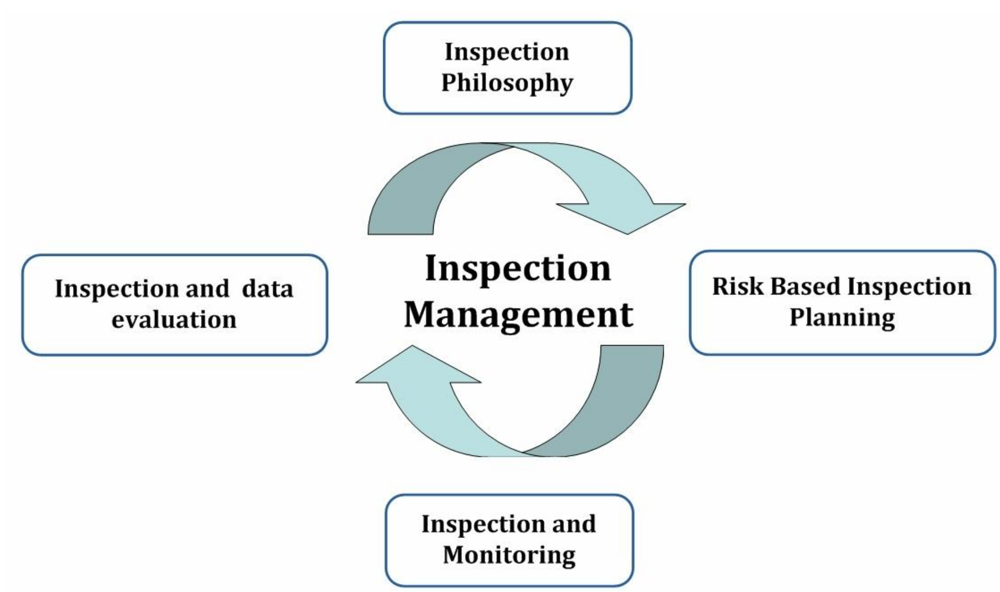

Figure 2.2 Inspection Management Loop (Adapted from DNV presentation 1, 2010)

2.2.a Inspection Philosophy

This step includes the acceptance criteria, which are often given by company policy and governing documents. The criteria show how much risk is accepted, and this often depends on the structure and the type of consequences that can occur. If, later in the work process, it is found that the risk is higher than the acceptance criteria, actions to decrease the probability or consequence have to be performed. It is normal to have one acceptance criterion for each of the three consequences: economic, environmental and safety.

2.2.b Risk-Based Inspection Planning

The planning of the RBI is where all the deliverables in Figure 2.1 are planned. The first part of the planning phase is to get an overview of the production which is often done by looking at process piping and instrument diagrams (P&ID) along with other documents. The first step in finding the equipment to inspect is called screening. Screening is often performed in a qualitative way by a team; here the aim is to find static equipment which has an insignificant risk and can thus be removed from further analysis. Equipment that is "screened" out will not be in the inspection plan, and because of the low risk it will most likely be repaired/replaced when it fails (run-to-failure, ref. Chapter 2.2). The remaining equipment will then be assessed in more detail, finding PoF, CoF and risk.

Probability of Failure (PoF) is a value that defines the probability that a component will fail within a defined time period, and since this thesis focuses on static equipment, a failure would mean a loss of containment of a pipe/valve that leads to unwanted release. PoF for such static equipment is set by calculating the degradation for the different corrosion groups and comparing this to the nominal wall thickness. This would then show the probability that it will fail within a certain time period. This assessment should also include any uncertainties included. PoF is then ranked as shown in Appendix A (DNV, 2009). PoF can be established qualitatively or calculated quantitatively, with the quantitative way being used as long as it is applicable.

Consequence of failure is the effect of an incident, given that it has already occurred. The type of consequence is often divided into three parts (DNV, 2009):

- Safety consequence – Consequences that affect human health (often expressed in potential loss of life (PLL) for personnel.).
- Economic consequence – Consequences that will affect the financial state of the company (often expressed in financial terms).
- Environmental consequence – Consequences that affect the environment, e.g. pollution, spills (often expressed in volume of pollutant). Reputation is also strongly affected by big environmental consequences.

It is recommended that each of these parts has its own CoF evaluation since the consequences can differ, and each of them requires proper focus. The CoF is then ranked according to severity, as shown in Appendix A. CoF is found qualitatively since it deals with consequences regarding reputation and environment, thus not making it applicable for a quantitative calculation. Other factors that also affect consequence are personnel on board (POB) the installation, amount released if the static equipment fails, and chemicals included in released substance, etc.

The values obtained from the PoF and CoF analysis are then gathered in a risk matrix, thereby giving the equipment a risk category. Figure 2.3 shows a simple example of a risk matrix, and Appendix B shows the risk matrix in higher resolution and detail.

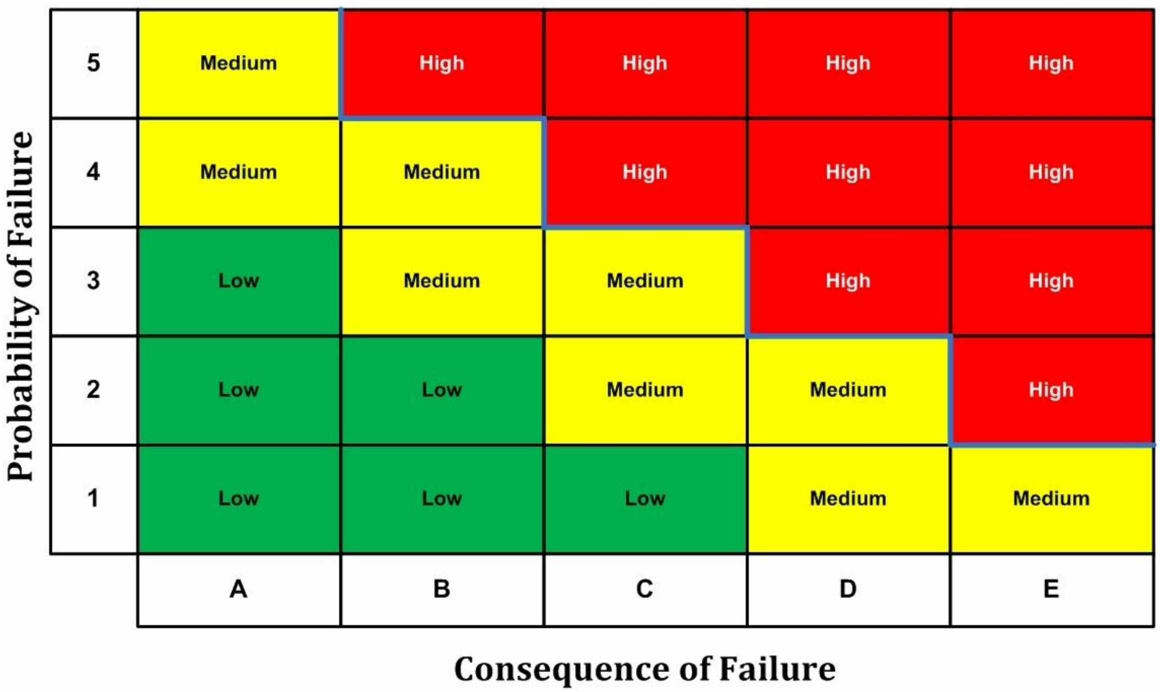

Figure 2.3 Example of risk matrix

This risk must be below the acceptance criteria, which is here shown by the blue line. If the risk is higher, actions to lower either the consequence or the probability must be performed. From this risk-based analysis the assessment will, in the end, have a list of equipment, arranged after risk evaluation. The equipment's risk evaluation will determine the next time-to-inspect. Equipment with high risk will be inspected more often then medium-ranked equipment, while low-ranked equipment will not be inspected at all. Equipment with low risk is screened out since it can break down without causing any significant consequence.

The risk ranking will then give an answer as to what to inspect, but there are other deliverables that have to be considered as well. When the equipment to be inspected has been chosen, it is important to find out where to do the inspection. This is often based on specifications of that particular equipment, knowledge (experience/historical data) and guidance from the manufacturer. When the hotspot (the optimal spot to inspect to get a satisfactory indication of the condition concerning degradation) is found, the inspection tool has to be selected. Non destructive testing (NDT) is the most common inspection method and, as the name implies, it is performed without damaging the equipment. Examples of NDT methods are radiography, thermography, and ultrasonic testing, as well as visual inspection (DNV, 2009; NDT, 2011). The type of inspection method used will depend on what information is needed to evaluate the condition of the equipment. When the information about what, where, and how to inspect are obtained, an inspection programme showing all these, including when to inspect, can be developed.

2.2.c Inspection execution

Based on the established inspection programmes, the inspections are carried out accordingly. Inspection data will then be stored in a database and equipment that is close to the acceptance criteria should be reported. Other data which was defined in the planning phase as important should be included.

2.2.d Inspection data evaluation

The data collected from the inspections are evaluated by a team of experts. Abnormal data or data that do not concur with expected data should be carefully evaluated, and inspections should be performed according to applicable standards. A report on integrity status, system effectiveness and a summary of issued recommendation for mitigating actions is issued annually. The inspection results are then put back into the assessment loop, and a complete reanalysis is then performed closing the inspection management loop illustrated in Figure 2.2. The knowledge gained through inspections will give a less conservative and more efficient inspection programme for the coming year as the knowledge of each system increases and the calculation can be performed with less uncertainty.

To summarize, the RBI assessment uses PoF and CoF to develop an inspection programme that is updated annually with new inspection data, information and knowledge, thereby making the inspection programme more efficient over time.

2.3 Condition monitoring of process parameters

Maintenance has always been a big focus area for plants since the cost from unplanned downtime is very high, certainly when considering the offshore industry. There are many types of maintenance strategies which are chosen with respect to safety and cost, as Figure 2.4 shows (Kumar & Kumar, 2004).

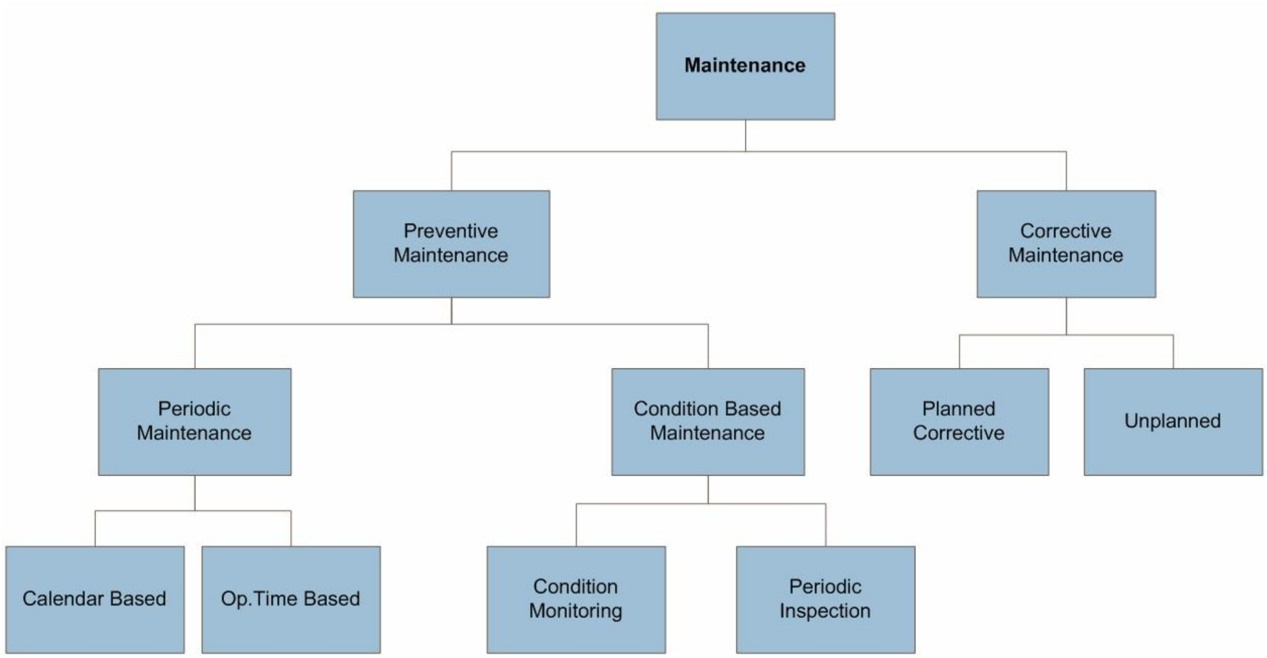

Figure 2.4 Maintenance techniques (Kumar & Kumar, 2004)

Corrective maintenance is a strategy in which the equipment is not repaired before it fails (run-to-failure). This can be done on equipment which has no safety hazard and will not cause downtime (risk ≤ low). Figure 2.4 also differentiates between planned and unplanned maintenance, where unplanned refers to failure with consequence (risk > low) which is what every installation wants to avoid.

The other strategy is preventive maintenance where, as the term implies, repairs are performed to prevent the equipment from failing. There are two "types" of preventive maintenance: periodic maintenance and condition based maintenance (CBM). Periodic maintenance is performed at set intervals based on the calendar or operational time, while CBM is performed based on the equipment's condition.

CBM can be thought of as a predictive maintenance tool which uses condition monitoring to predict failure. Condition monitoring can be periodic or continuous monitoring of equipment, where important parameters showing the condition are monitored. This method is used a lot on dynamic equipment offshore (e.g. turbines, pumps, machines) through monitoring parameters like vibration, heat, loading, etc. However, in this thesis we will monitor process parameters like temperature, pressure, flow rate, etc. since these are important when considering degradation of static equipment. The process parameters will be monitored continuously and the data collected are used to evaluate the equipment condition considering degradation. Having access to condition data makes it possible to perform servicing, or other actions, before the failure occurs. Figure 2.5 shows that failures are often not detectable at early stages which make it important to observe them as soon as possible to prevent failure. The Y-axis, called condition, can be divided into two different types of conditions: performance and integrity. Performance can be monitored through looking at parameters that shows the efficiency of the equipment (e.g. turbine). Integrity, on the other hand, is monitored through performing inspections, since most of the equipment is static (e.g. pipes, valves, vessels, etc.).

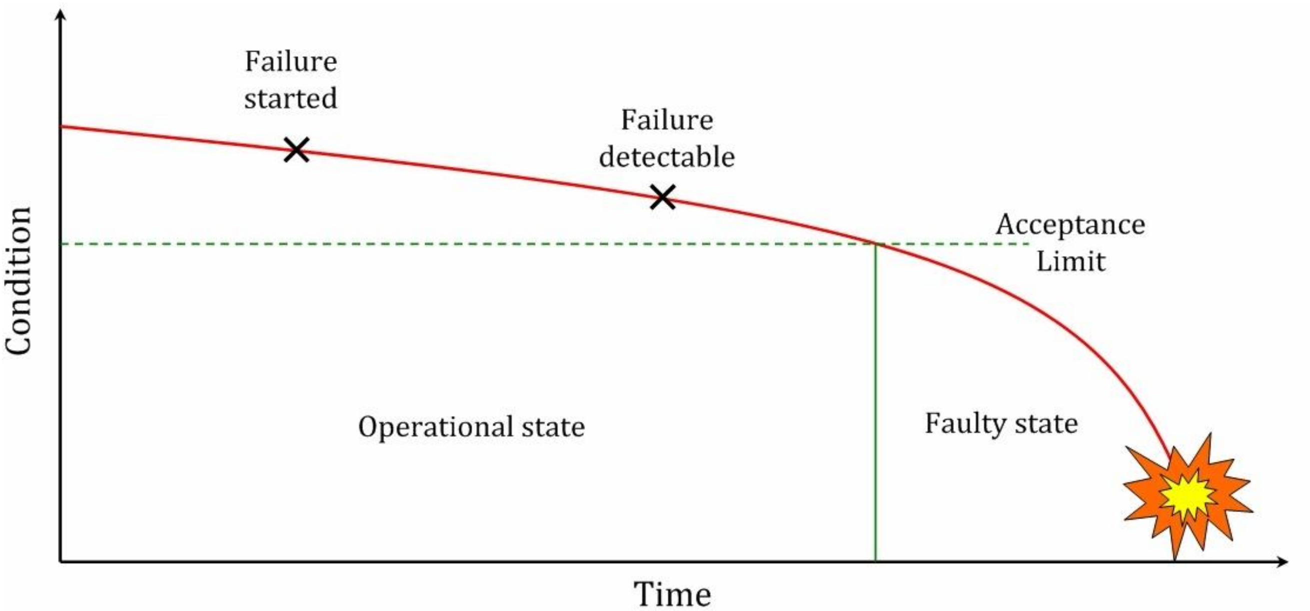

Figure 2.5 Example showing equipment condition over time

CM is a method which has emerged from periodic maintenance, and this has made the monitoring process very static in nature. But the introduction of information and communication technology (ICT) revolutionized the monitoring process since it could be done continuously. ICT made it possible to get live data and information shown directly on the operator's screen. Maintenance and service plans can now be easily developed, and, with the use of correct parameters, the fault itself can be located by just analyzing the data.

CM can be used as a direct or indirect tool to help the onshore engineer (OE). Information that is assessed directly, like vibration, is made up of parameters which can cause great damage by themselves. Information assessed indirectly consists of measurements that have to be combined with other information to give any valuable results regarding the equipment's condition. An example is the use of pressure, volume and temperature to measure the efficiency of a turbine.

Implementing CM can be expensive if the existing facility does not have the required sensors and sampling stations to get the information needed. Many models for implementing CM have been developed, and some simplified steps are given as an example:

1. Survey of the plant
2. Choose parameters
3. Monitor
4. Evaluate
5. Perform actions

Firstly, a survey is performed where engineers overview the production process and find critical equipment with respect to production and safety. The equipment that could affect the safety risk is the first priority, but cost is also a factor to be included (downtime). Equipment will then be evaluated qualitatively by a group that looks into how failures could occur on each machine. The most common method used is the failure mode, effects, and criticality analysis (FMECA) which shows what can happen and the cause. The FMECA analysis would then give an indication of which parameters should be monitored to prevent failures. After the parameters have been selected, the CM technique has to be selected. For example, if temperature is a crucial parameter (e.g. electro motor), a sensor that can measure this has to be selected. When the sensors are in place, the limits should be set for each parameter. Fluctuations of the parameter data should be tracked, and trends should be included to aid the operator. Information like this would make it easier for the operator and maintenance engineers to evaluate the condition and perform actions accordingly.

It is important to look at the CM method as an endless “loop” where information sharing and evaluation of each step is important. The most effective CM system can take years to fully develop, thus a continuous evaluation of each step is essential for improvement (DNV, 2003).

CHAPTER 3
Development of a work process for condition management

3.1 Introduction

This chapter will focus on how to integrate condition monitoring of process parameters with RBI. RBI analysis is used to manage inspections of static equipment topside, amongst other equipment, with respect to risk. The conventional method of performing RBI analysis is static in nature since degradation and cracking mechanisms are calculated with annual process parameters, even though these parameters could change over time. Through integrating condition monitoring and RBI, the changes in the parameters would be dynamically included in the analysis. Live process data (e.g. flow rate, temperature, pressure) is collected and processed, updating the original degradation condition. These changes might alter the PoF, and ultimately the risk set in the original RBI analysis. Since RBI is a risk-based inspection method, the change in risk will update the original inspection plan, thus assuring that inspections are executed at the right time.

The integration of condition monitoring and RBI is called condition management. This is a management system that uses live process data to continuously assess the degradation condition of static equipment, which is then used to manage the inspection planning and execution.

Some of the benefits from such a management system are (Chai et al., 2010):

- Performing the inspection at the "right time" would reduce costs related to unnecessary inspections of static equipment, as well as avoiding downtime related to inspections executed too late.
- The continuous updating of degradation rates will avoid downtime related to degradation or cracking.
- Personnel would understand the impact different parameters have on static equipment's reliability and condition with respect to degradation.
- The information and data delivered would aid the OE in making the correct decision regarding the planning and execution of inspection.

There are many challenges with condition management: what parameters to use, how to collect data, how to process data, how to integrate live data and inspection data, how to use results in decision-making, etc. These challenges will be addressed in this study through a work process for implementing the condition management system. The work process in this thesis will use an existing framework as a foundation for the condition management model (Chai et al., 2010). The thesis is based on eight steps that are modified from the existing framework:

1. Select sensors and sampling stations – Select sensors and sampling stations that can be used for assessing equipment degradation.
2. Create an interface between sensor and operator – The second steps focuses on how to connect instruments (sensors/sampling stations) to the operator's database.
3. Data collection – The data collection stage shows how, and where, to collect and store data, as well as compression of data.

4. Data processing – This focuses on how the collected data should be processed and present meaningful information to the OE.
5. Risk estimation – The risk is updated based on the recalculated PoF given by the processed data.
6. Setting limits and distributing alarms – This stage focuses on how to set limits for alarms, further analysis, etc.
7. Inspection planning and execution – This shows how inspection should be planned, based on the updated risk, and executed.
8. Decision support – The final step focuses on how data, information and knowledge gathered from the previous steps should be used to optimize decision-making concerning inspection planning and execution, as well as the system itself.

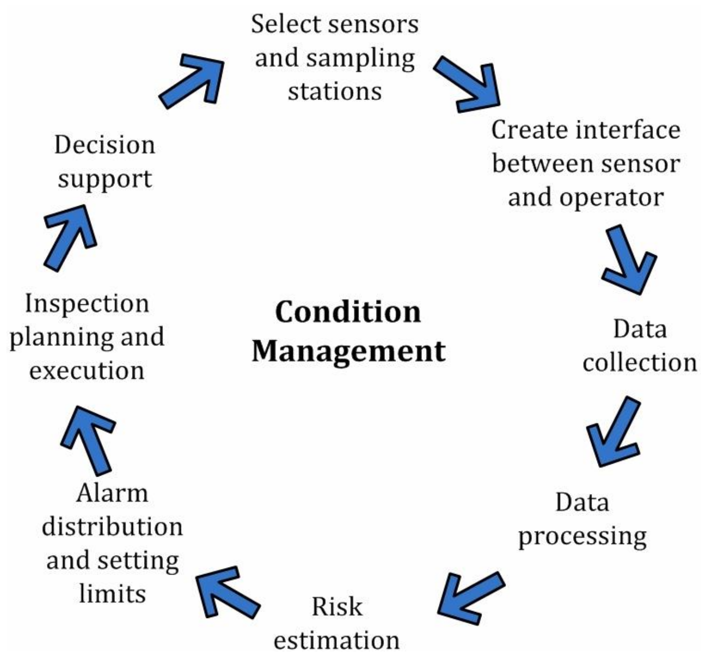

Figure 3.1 Condition management loop (Adapted from Chai et al., 2010)

This thesis will use these steps to give guidance on how such a management system should be implemented. Figure 3.2 presents the condition management system based on this thesis, and it shows how the system interconnects. Using this figure when reading through the thesis is encouraged since this will make it easier to understand how the complete system works. This figure will also be further discussed in Chapter 3.10.

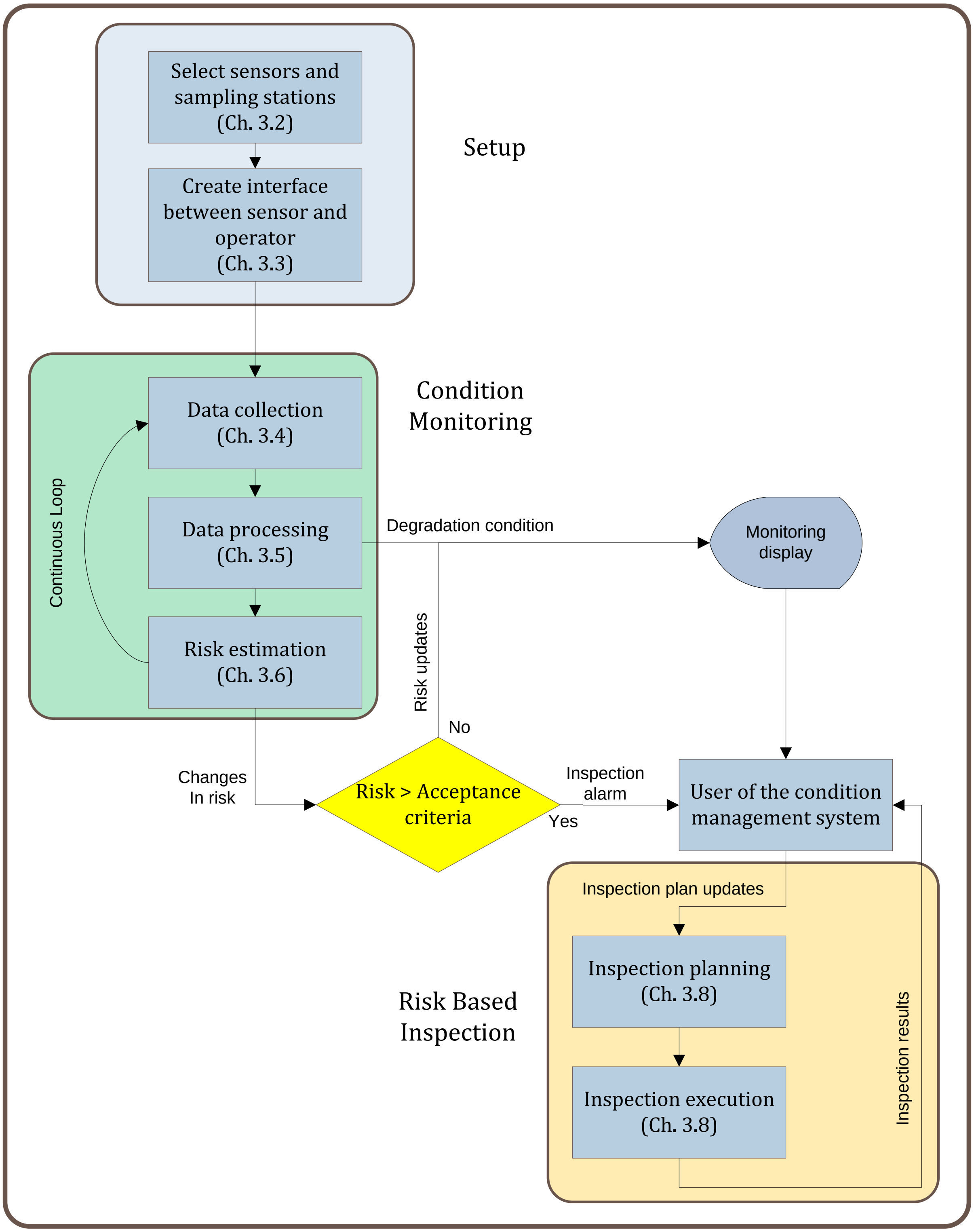

Figure 3.2 The condition management system

3.2 Select sensors and sampling stations

The selection of sensors and sampling stations is performed to provide an overview of the available instruments installed on the existing plant. The reasons for performing such an overview are to:

- Divide the system into corrosion groups.
- Decide on the degradation mechanisms in each corrosion group.
- Select the sensor and sampling station that can be used to monitor parameters that affect degradation.

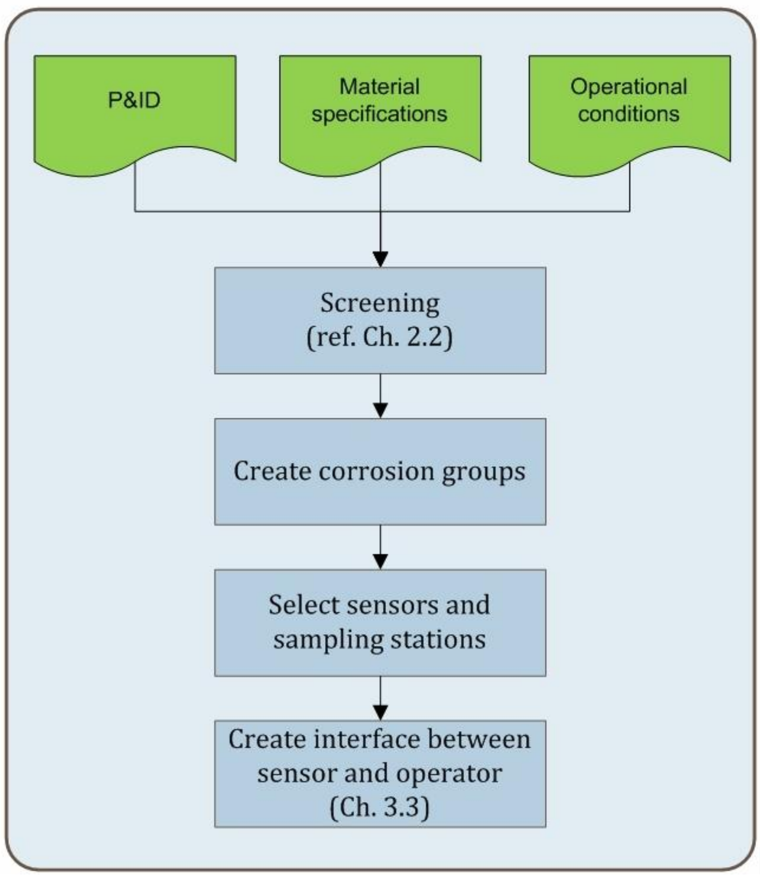

Figure 3.3 Selecting sensors and sampling stations

This step is performed using piping and instrument diagrams (P&ID) of the installation. These diagrams show how the system is designed and what type of material is used. By using such a diagram, the whole system can be divided into corrosion groups, as shown in Figure 3.5. A corrosion group is a section of static equipment which is considered to have the same operational conditions and material specifications, thus the same degradation mechanisms. Some materials are more susceptible to certain degradation mechanisms than others, and this should also be considered (see Chapter 3.5). In addition, some corrosion groups are non-susceptible to degradation (low PoF) or have no consequence if they fail (low CoF), and these groups can then be screened out without being further assessed.

When the corrosion groups are determined, the next step will be to decide which degradation mechanisms can occur in each corrosion group. Every degradation mechanism requires certain conditions, and the material specification in combination with operational condition will give the possible mechanisms which can occur. For more information concerning degradation mechanisms, see the recommended practice for RBI (DNV, 2009). Figure 3.4 shows what operational conditions have to be present for certain degradation mechanisms.

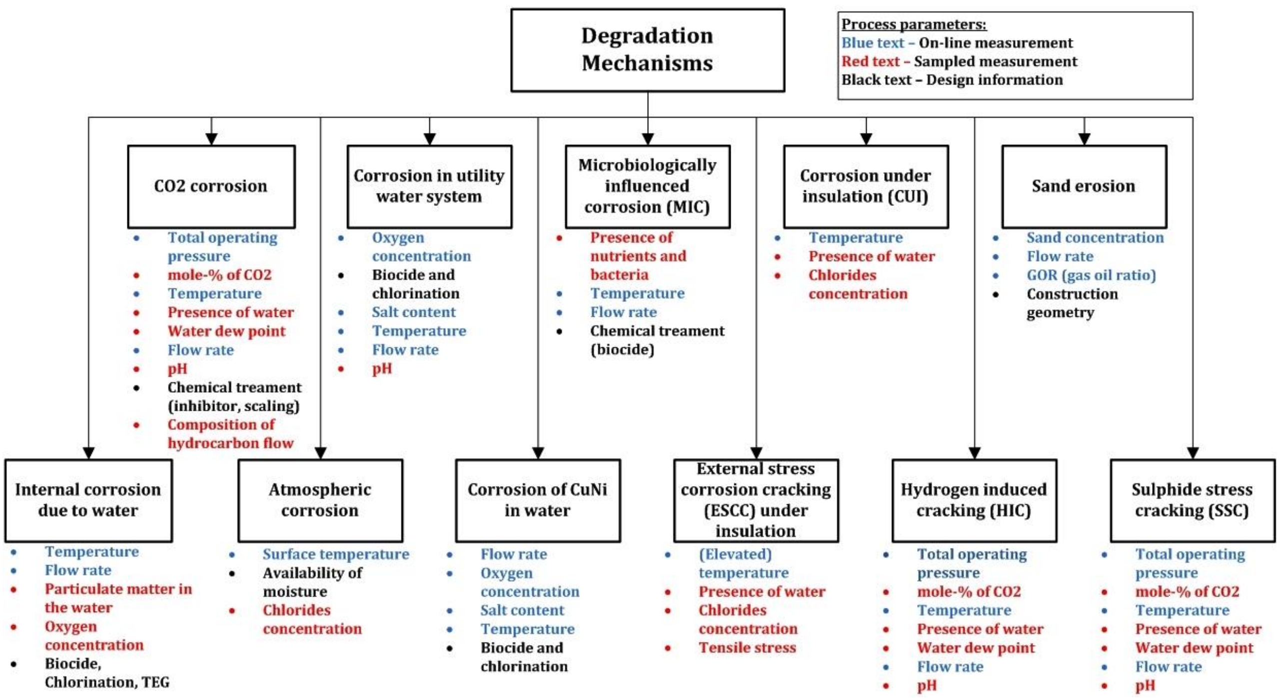

Figure 3.4 Degradation mechanisms and corresponding parameters (Chai et al., 2010)

Figure 3.4 shows that temperature, pressure, flow rate and production flow (amount and ratio of different substances in flow e.g. oil, gas, chemicals, salt, sand) are "on-line measurement" parameters which means that they can be monitored automatically using sensors. These parameters will be continuously monitored while "sampled measurements" are performed at certain intervals using sampling stations. The "design information" is fixed parameters like material and layout, but it can also be wall thickness which will change over time if corrosion occurs. All three types of information, as well as inspections, have to be included to have an accurate management system.

When the degradation mechanisms and the parameters which have to be monitored are selected, the next step will be to determine which sensors and sampling stations to use. The main idea of condition management is to use existing sensors and sampling stations so the system can be implemented without performing modifications to the installation. This will reduce the cost of introducing such a system by avoiding downtime of production as well as the modification cost itself. However, if the existing sensors and sampling stations cannot deliver the data required, modifications should be performed.

Offshore installations are often highly equipped with sensors and sampling stations, but these instruments are placed with respect to the production process and not the degradation process. Locations that could give valuable information concerning degradation would then not always be present, which means that the data have to be considered with respect to the location of the instrument. Thus, it should be a priority to select the “worst case” spots (e.g. dead legs, low points, etc.) since the corrosion, in theory, should be worst at these spots (Chai et al., 2010). If such spots are not available, data from other locations have to be calibrated to give the most accurate data available.

The selection of sensors and sampling stations is done by using the P&ID; see Figure 3.5. This figure already shows the corrosion groups in green, yellow and blue which respectively correspond to gas, oil and water. Then the information considering the parameters for assessing degradation condition is used to select the correct sensor or sampling station. The sensors also have to be transmitters, which means that they need to send signals continuously. Since temperature, pressure and flow rate are important for assessing degradation condition, these are shown in the P&ID. This P&ID can also be found with higher resolution and detail in Appendix C.

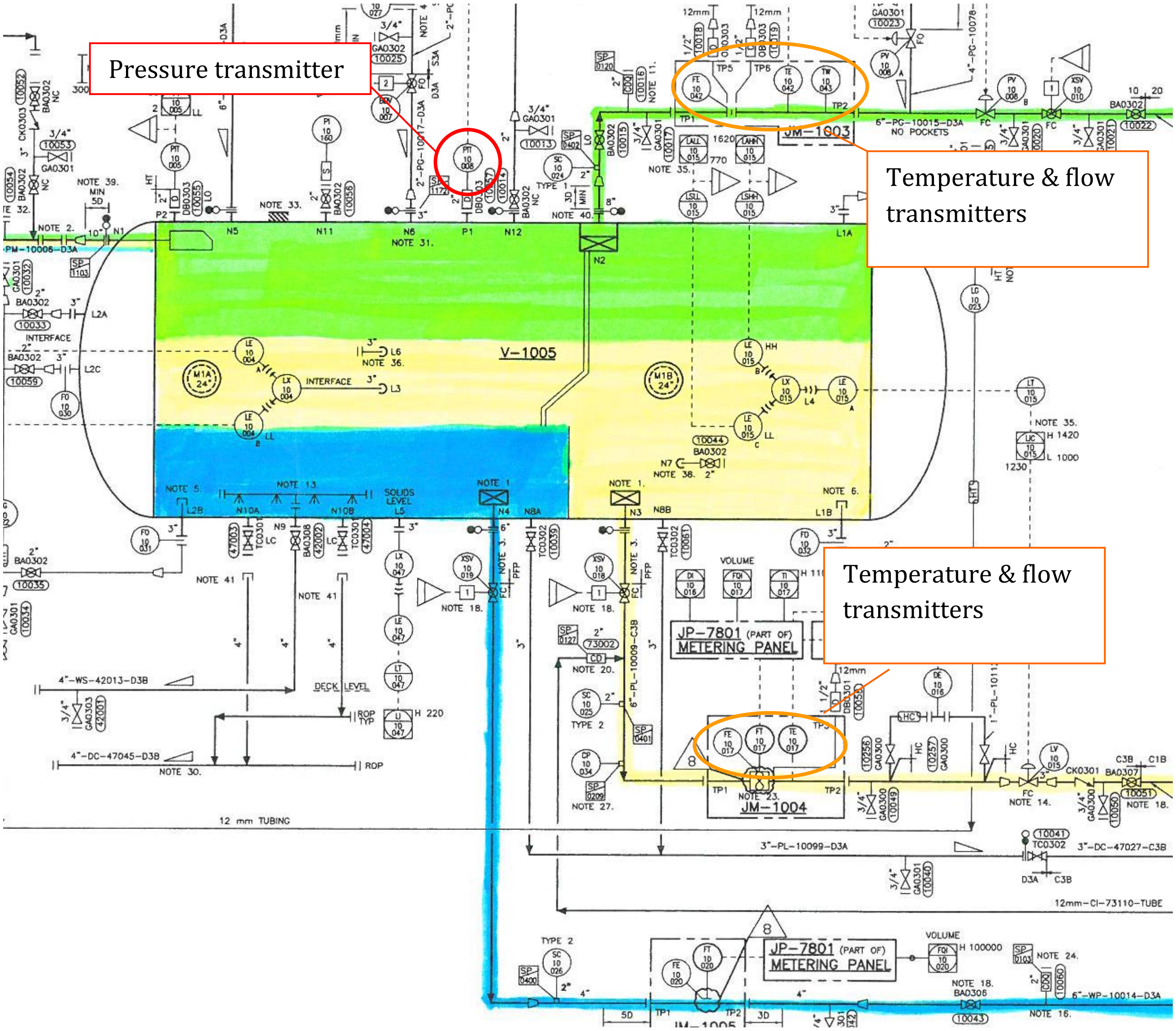

Figure 3.5 Example of P&ID (Adapted from document acquired from private communication, DNV)

Locating sensors and sampling stations is easy when using a P&ID, but it is important to ensure that the sensor can collect and transfer the required data. Sensors are most often analogue where physical properties (e.g. temperature, pressure) are converted into a corresponding electrical signal (e.g. voltage, ampere or resistance) (Sensors, 2011). It is important to ensure that the sensors and sampling stations serve their purpose, and some general requirements are listed below (Markeset, 2011):

- Robust – They should be able to withstand the local environment they are operating in offshore (e.g. temperature, vibration, water, wind).

- All sensors must be analogue – Digital sensors have just 1 or 0 as output, while analogue sensors can have a wide spectrum of outputs. Thus the analogue sensors can be used to measure the changes in temperature, flow, pressure, etc.
- Easy to calibrate (remote calibration is a plus).
- Ex approved – Approved for explosion-protected electric apparatus (e.g. no sparks that can ignite flammable media).
- High accuracy – Very accurate at important temperature and pressure levels with respect to corrosion (e.g. ± 0.5 °C between -20 - 120 °C and ± 1 bar between 0 - 200 bar).
- Easy to connect – Safer with cable, easier with wireless.
- Should have a high sample range to ensure correct measurement at abnormal conditions (e.g. temperature between -100 to 250 °C, pressure between 0 - 400 bar).

3.3 Create an interface between sensor and operator

The interface step includes two main tasks:

- Identify each sensor and sampling station with a unique identification (ID) tag.
- Create an interface between the sensor (hardware) and offshore operator (software).

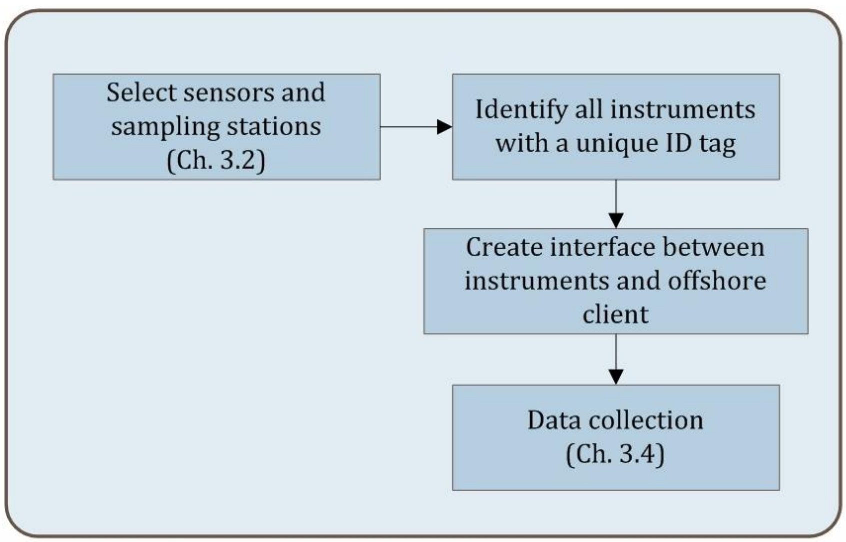

Figure 3.6 Create an interface between sensor and operator

The sensors and sampling stations should be identified with a unique ID tag. Each sensor and sampling station would then have a unique tag which will make the process of collecting the correct data simpler and more efficient. Accessing the database server and selecting data with respect to ID tags will be further explained in the next chapter, while this chapter focuses on how data is transferred from the sensor to the operator offshore.

An interface could be thought of as the point where inputs and outputs communicate, and in this case it makes un-useful information into useful information. The sensor measures a physical property and converts this into an electric signal, which is why the interface needs to convert this into “useful” information. The interface is most often an I/O (input/output) controller which is programmed to convert the input to the required output. Some examples of controllers are programmable logic controller (PLC) and distributed control system (DCS). These are further connected to a server which receives all information from the process; see Figure 3.7.

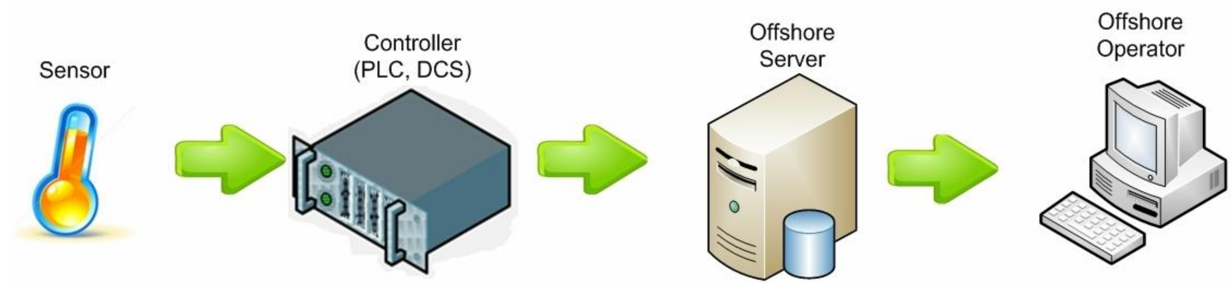

Figure 3.7 Interface between sensor and offshore client

There is a high variety of automation companies that deliver controllers and sensors (e.g. ABB, Siemens, Honeywell, etc.). In the past, each manufacturer had individual server and client software which had to be used to provide an interface between the controller and the offshore operator. They also had a unique programming language, and setup, which meant that you had to buy a complete system from one provider to make it work, and this system could not be integrated with other systems. This is the same problem that people previously had with printers, where each printer manufacturer had its own standard, and each printer needed a unique driver to work. Plants with sensors and controllers of different brands had a hard time integrating all this into one system; thus, something had to change.

Not long ago the manufacturers got together with Microsoft to make one standard. This meant that each manufacturer followed one standard called the Object Linking and Embedding (OLE) for Process Control (OPC) standard. When all the manufacturers followed the OPC standard, the different controllers could easily be embedded in the control system from Microsoft. This is the same solution that the printer manufacturers had when they got together and made one standard, which meant that Microsoft could just embedded this standard in their operating system to install all types of printers automatically. Figure 3.8 shows the difference between the “conventional” and “modern” interface:

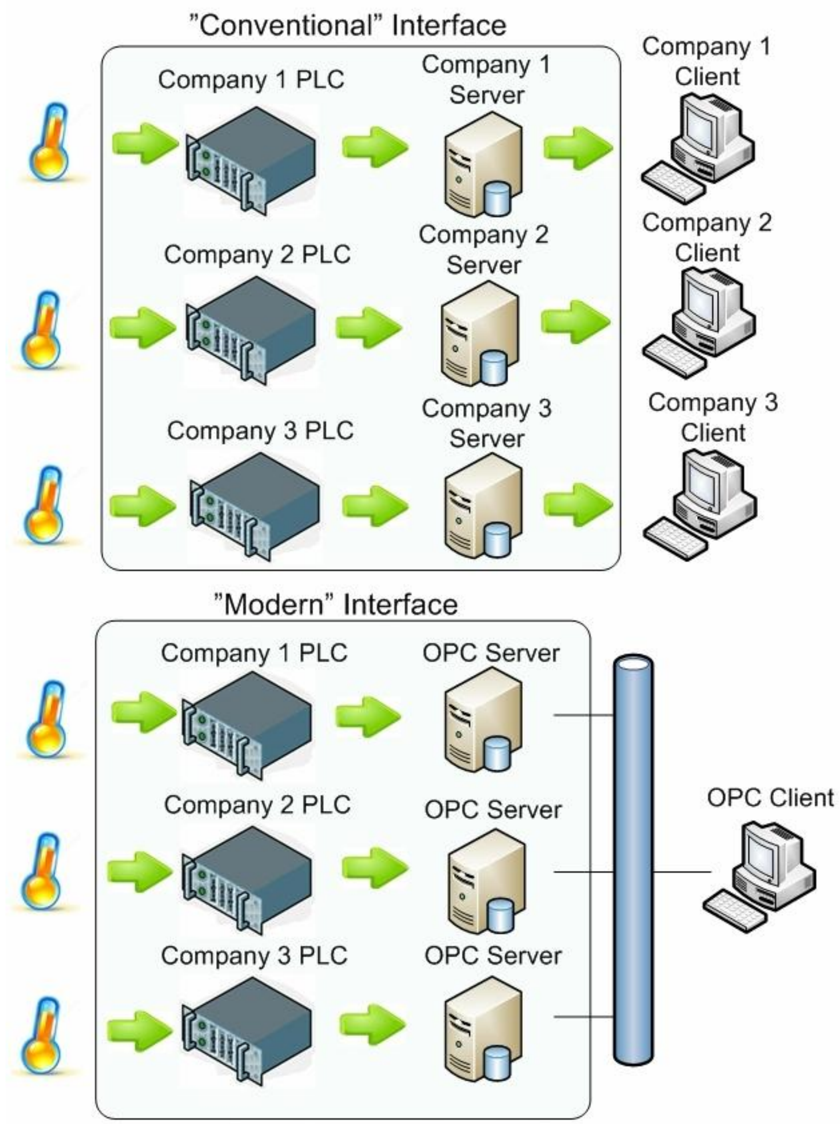

Figure 3.8 "Conventional" and "Modern" interface

We can think of the OPC as a "plug and play" server which can easily be connected to the controllers (PLC) on the plant. The number of servers and clients needed is about the same, but the implementation and installation of the control system is much faster and simpler. OPC will also make it much easier if new sensors have to be installed, since they can just be plugged in and identified with an ID tag.

Process hardware manufacturers develop an OPC compliant interface which makes it possible to choose the best product without thinking about the integration part. The OPC server has to be connected to an OPC client since it is based on the same standards, and this client is used by the operator offshore to monitor the process (The OPC Foundation, 2011; Hauge et al., 2009).

3.4 Data collection

Data collection focuses on how data should be collected and stored. There are many data sources, like sensors, sampling stations, inspection results, laboratory analysis, etc. The data from inspections, laboratory analysis and sampling stations are manually collected, and stored with the correct ID tag with respect to the corrosion group. The results from sampling stations and laboratory analysis should be stored on the main database server with the appropriate ID tag, making it possible for the onshore engineer (OE) to download the newest result and integrate it with live data in the data processing. Inspection results are given to the client, and stored in the local database. However, this chapter will focus on the continuous collection of process data from sensors, and how this should be done efficiently.

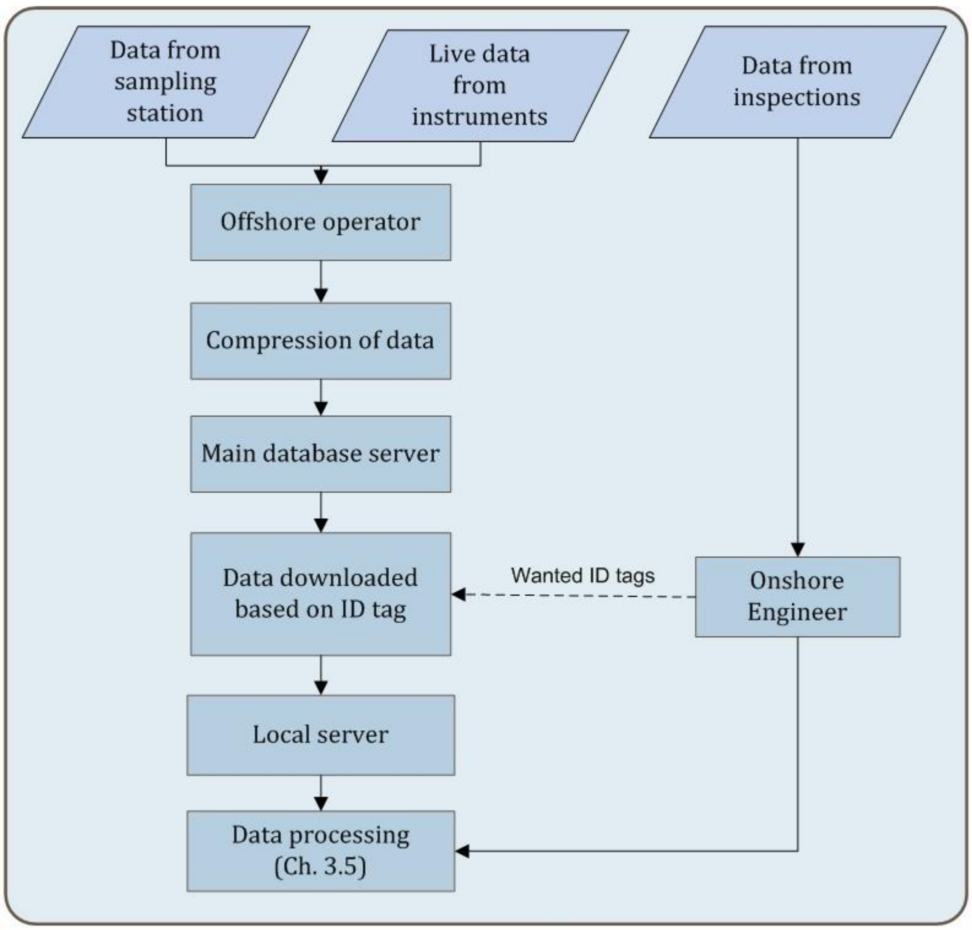

Figure 3.9 Data collection

As shown in the interface stage, the data is first collected by the offshore operator who just stores temporary data before it is forwarded to the server's database. This is done since it would not be economic to build server stations offshore on a platform, when it can be done onshore. Data is transferred through fibre cables or satellite, which are the most common link between offshore platforms and onshore offices (EDB, 2011). All data is stored on the main servers as often as the sensor collects data, which can vary from seconds to hours. The data is then sorted according to the ID tag given by the interface. But the number of ID tags on a platform can vary from 30,000 to 50,000 tags, and storing such an amount of data every second will decrease performance and increase cost of storage space. There are many commonly used database systems, e.g. Microsoft Access (Microsoft), MySQL (MySQL), PI (OSIsoft) (Microsoft, 2011; MySQL, 2011; OSIsoft, 2011). These systems use two common databases called relation data base management system (RDBMS) or time-series database.

The RDBMS stores data in separate tables, but it also stores the relation between the data in another table. This makes it possible to create large databases in which the relation between data is sustained. The time-series database stores all data with respect to time, which means that all the different tags on the platform would get an individual table. How the data is stored is not the issue here; instead, we will focus on how the data is compressed before it is stored.

The RDBMS compresses data using average values over a certain time period. The length of this time period will depend on how old the data is; so, if you have one-week-old data this might be compressed into hours or more (Ault, 2003). An example of how this is done is shown in Figure 3.10:

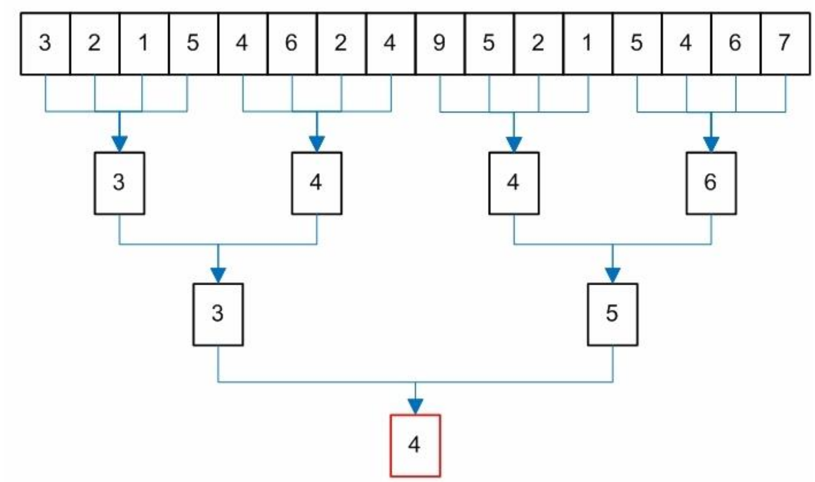

Figure 3.10 Compression of data in Relational Data Base Management System (RDBMS)

This way of compressing data works fine; however, it can average out parameter variations that are important for accurate degradation calculations. Example: The "9" and "1" in the top row are averaged to a "4" which could be misleading when used later in the analysis. Degradation occurs slowly, and averaging can be done since changes over a short time period do not initiate degradation. However, there are much better and more accurate ways of compressing and averaging the data.

The time-series databases are compressed in ways that give more valuable information to the OE. The compression in the time-series database is done by using an interval for how much a parameter can change before it is stored, thereby making the system as accurate as the OE requires. Since degradation requires a substantial change in temperature, changes within an interval of ± 5% could still be accurate enough to assure degradation condition (DNV, 2009).

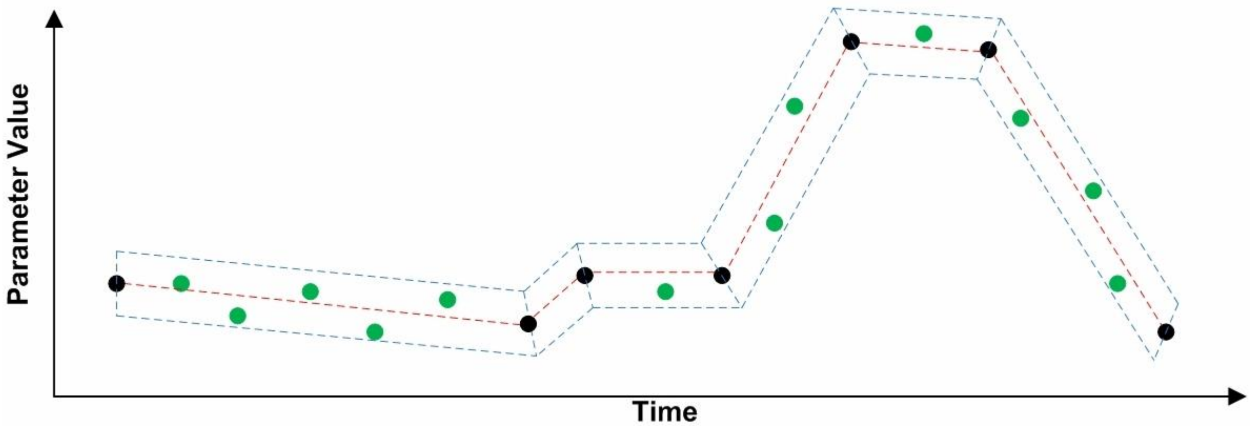

Figure 3.11 Example of compression of time-series databases (Adapted from OSIsoft, 2009)

This type of compression is done by looking at the trending of the signal, and rejecting values that do not change enough to breach the accuracy interval. If a value comes outside the interval slope, a new interval would be made following the "new" slope of the signal. From the example above, only the black dots will be saved, and the green dots will be deleted, where the end result is a line between the black dots, as shown by the red line. This will, in the end, give results with high resolution but also the fluctuation of the parameter over time. If data is downloaded at a time between two black dots, the server will show the value given by the red line.

This will compress data without removing high fluctuations as in the RDBMS compression. Instead, it will compress the data and give results with high resolution. Such compression will also automatically remove noise which is common in signals from sensors.

The database systems shown above also include automatic quality checks with respect to missing or conflicting data. This is mostly done by using the last known data, and connecting it to the next data collected. In addition, many interfaces are known to include a simple check of data which removes similar problems. However, if none of these quality checks work, the OE will perform a qualitative check before updating the inspection plan, thus avoiding faulty data interfering with the inspection plan (ref. Chapter 3.8).

All the data from sensors and sampling stations are stored on the main server database, while inspection results are uploaded by the OE. However, since all the data from the installation is not needed, the data needed for calculating degradation are filtered out using ID tags. The OE would then only download data from sensors and sampling stations that were selected in the first step by using the ID tag they were given in the second step. In addition, the OE can perform a simple search to download data from any tag stored on the main database server (see Figure 3.9 and Figure 3.12).

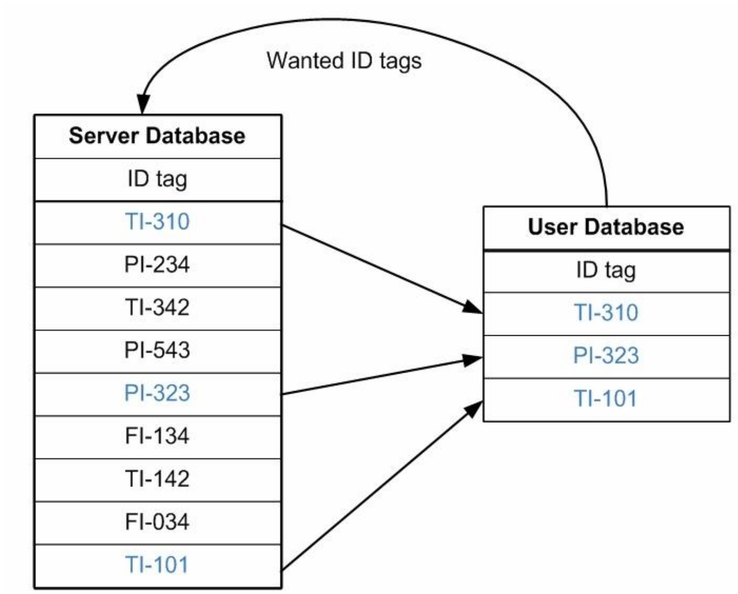

Figure 3.12 Collecting data based on ID tags

The OE should set up an individual dedicated local server, which downloads the required data. The local server will download data from the main server using ID tags, and then store and process it.

3.5 Data processing

In the data processing stage, the data collected from inspections, process parameters and sampling stations are calculated and transformed to give the OE information about degradation rates and the integrity of the plant. The subjects that will be covered are:

- Selecting degradation model
- Averaging data based on degradation model
- Processing data

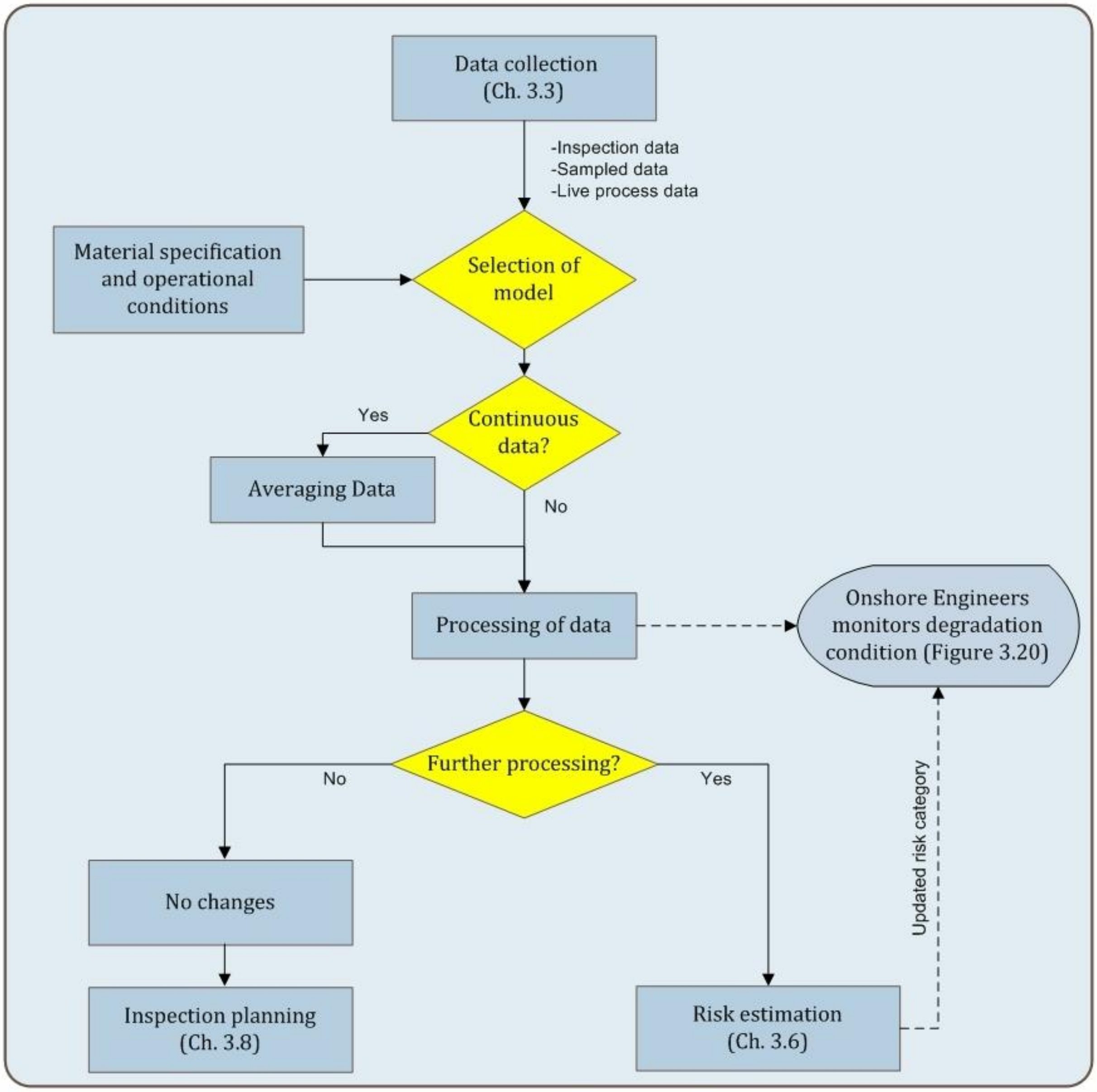

Figure 3.13 Data processing

3.5.a Selecting degradation model

The first step of the condition management system (ref. Chapter 3.2) divided the process plant into corrosion groups based on material specification and process flow. Using this overview, the OE can select which model to use based on material (e.g. carbon steel, stainless steel, titanium, etc.) and operational conditions (e.g. temperature, pressure, chemicals, oil-gas ratio, volume of water, humidity, etc.). There are three models that should be considered with respect to damage rates: insignificant model, rate model and susceptibility model (DNV, 2009).

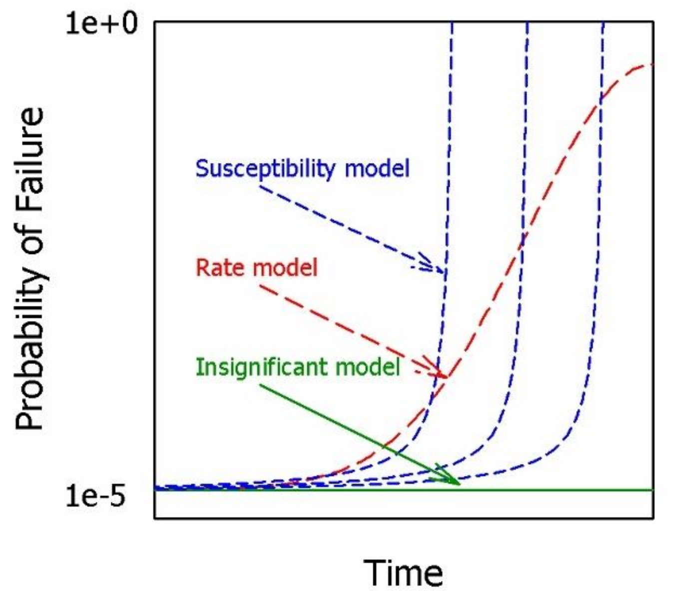

Figure 3.14 PoF over time for the different degradation models (DNV, 2009)

The **insignificant model** is used on equipment where no significant degradation is expected. The model allocates a fixed PoF of 10^{-5} per year, which means that no planned inspection is necessary. This model is used on very tough materials like titanium, and these types of material are screened out early in the process (ref. Chapter 3.2).

The **rate model** is used on equipment where degradation accumulates over time. This model is mostly used on carbon steel since its degradation mechanisms accumulate gradually (see Figure 3.15). The degradation mechanisms in the rate model are often affected by various parameters, and a sensitivity analysis should be carried out to get the most accurate results. Using such analysis will give a degradation rate for each degradation mechanism, instead of looking at each parameter with respect to rate. Typical degradation mechanisms are:

- CO_2 corrosion
- Corrosion in utility water systems
- Sand erosion
- External corrosion of insulated carbon steel piping
- Erosion (e.g. sand, particulate matter)
- Microbiologically Induced Corrosion (MIC)
- Corrosion under Insulation (CUI)

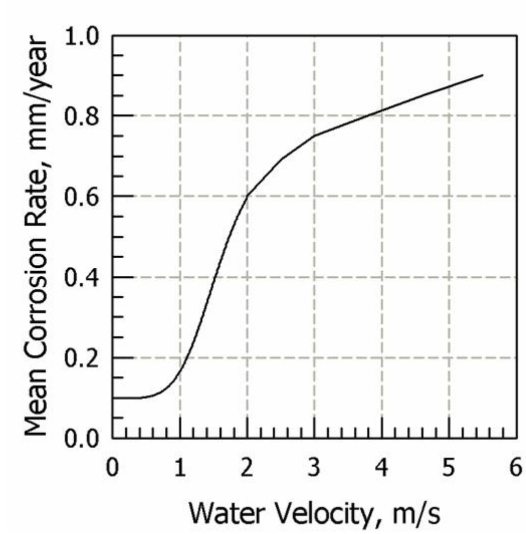

Figure 3.15 Typical rate model graphs (DNV, 2009)

The **susceptibility model** is the most interesting model when considering the use of live process data. This model is made for damage which occurs very quickly and locally (e.g. cracking and pitting), thus the inspections will not be feasible (DNV, 2009). This model uses a fixed PoF for each parameter since degradation initiates too quickly to consider damage rates (Figure 3.16). The susceptible model focuses on the temperature parameter since this is the main trigger for most degradation mechanisms, and tends to outweigh other parameters (e.g. pressure, flow rate, etc.).

The model covers one degradation mechanism in carbon steel and copper-nickel alloys, but it is mostly used on high alloy steel (e.g. stainless steel). Some degradation mechanisms in the susceptibility model are:

- Corrosion in utility water systems
- Local corrosion
- External Stress Corrosion Cracking (ESCC)
- Internal corrosion by water - CuNi

The susceptibility model includes all types of high alloy steel, and three common types are: SS316, Duplex, and 6Mo. These materials are very sensitive to changes in temperature; an increase of 10 °C in temperature on a 6Mo stainless steel pipe would make the PoF rise from 10^{-4} to 0.1, as shown below (DNV, 2009).

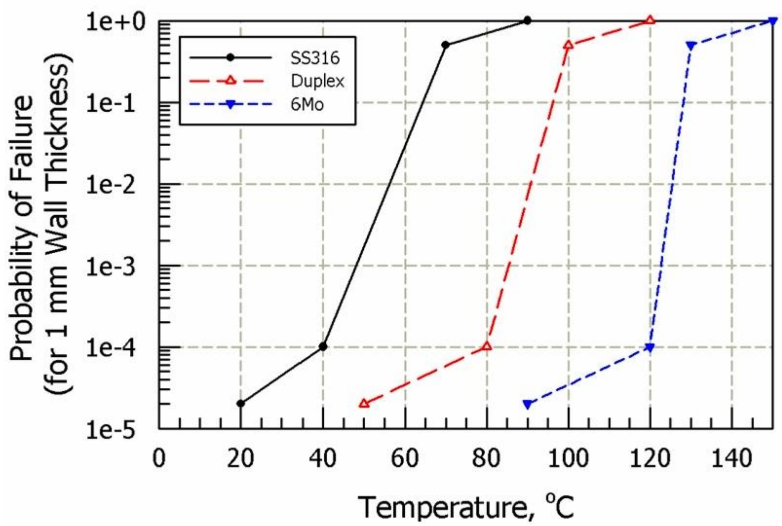

Figure 3.16 – Susceptibility model showing PoF for local CUI (DNV, 2009)

3.5.b Averaging data based on degradation model

Averaging data is done for continuously monitored data; since sampled data are collected at long intervals, they would not need averaging. Since degradation mechanisms are not initiated at the moment a parameter change, values should be averaged to give more meaningful information to the OE. Spikes in the parameters over 10 minutes will not initiate degradation, while a high parameter averaged over a week might be a different case. This will depend on what model the respective degradation mechanism uses, and the parameters that influence degradation.

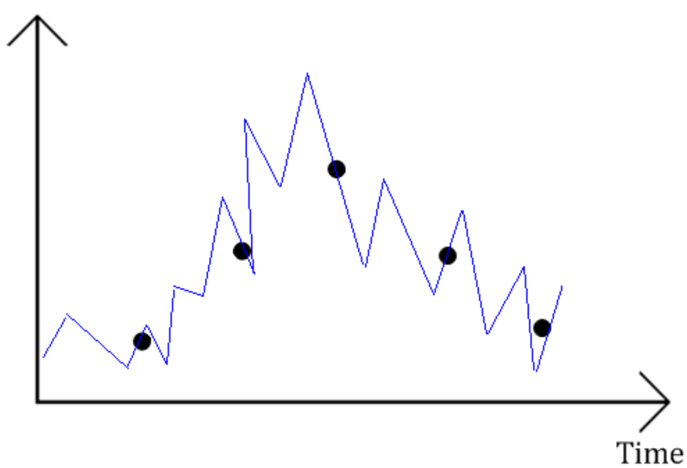

Figure 3.17 Averaging data

When we consider the rate model, the degradation accumulates; thus, the parameters for these degradation mechanisms should be averaged over a time period with respect to how quickly they initiate. Since the rate model most often considers degradation rates around millimetres per year, the averaging time period could be set to days. Degradation mechanisms in the susceptibility model initiate faster and should therefore have a shorter averaging time period (e.g. an hour). However, the time periods to be averaged could also be based on each degradation mechanism, instead of the degradation model, making the system even more accurate.

Setting such averaging time periods is hard since there is no set time to how fast degradation initiates. Thus, these time periods should be set qualitatively by experienced degradation experts, and updated when new information is available through this system. Information gathered over time provides the ability to differentiate between the mechanisms in the same degradation model, making the system more effective and accurate. In the beginning, it is better to make conservative averaging time periods since it is better to be safe than sorry.

3.5.c Calculating and processing data

Downloaded data are originally used by looking at trends showing the fluctuations over a certain time period. This makes it possible for the OE to select trends that will give the most valuable information. However, to give even more valuable information, the data should also be processed. The local server downloads data, averages it with respect to degradation model (or degradation mechanism), and processes the data to evaluate the condition with respect to degradation. Inspection results are manually uploaded by the OE where applicable, and they are used to check that the calculations are correct (ref. Chapter 3.9) and to update wall thickness.

Assessing degradation condition for susceptibility is a simpler task since it mainly depends on temperature. This would then be a conversion from temperature to PoF (Figure 3.19). The rate model is more complex since it often depends on several parameters (Figure 3.18). If there are two or more parameters which affect the degradation mechanisms, a sensitivity analysis should be performed to give a more accurate degradation rate. The results from such sensitivity analysis will show the correlation of each parameter with respect to degradation rate (Figure 3.18). Some of the calculations are often comprehensive, and software like Microsoft Excel is often used to perform these since it supports large calculations (Microsoft, 2011). However, some parameters also affect the degradation mechanism more than others, and parameters like temperature and pressure often outweigh others, thus simplifying the calculations.

The processed data should then be presented and compared to acceptance limits, thus showing the condition with respect to degradation. Methods on how to set limits are further discussed in the chapter concerning alarm distribution (ref. Chapter 3.7).

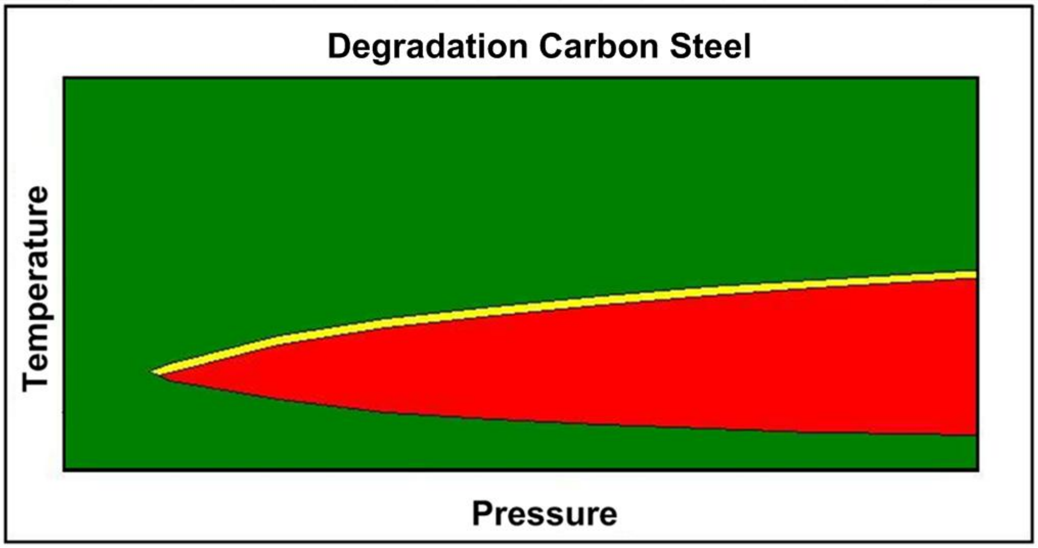

Figure 3.18 Example of acceptance limits for the rate model (Adapted from DNV presentation 2, 2008)

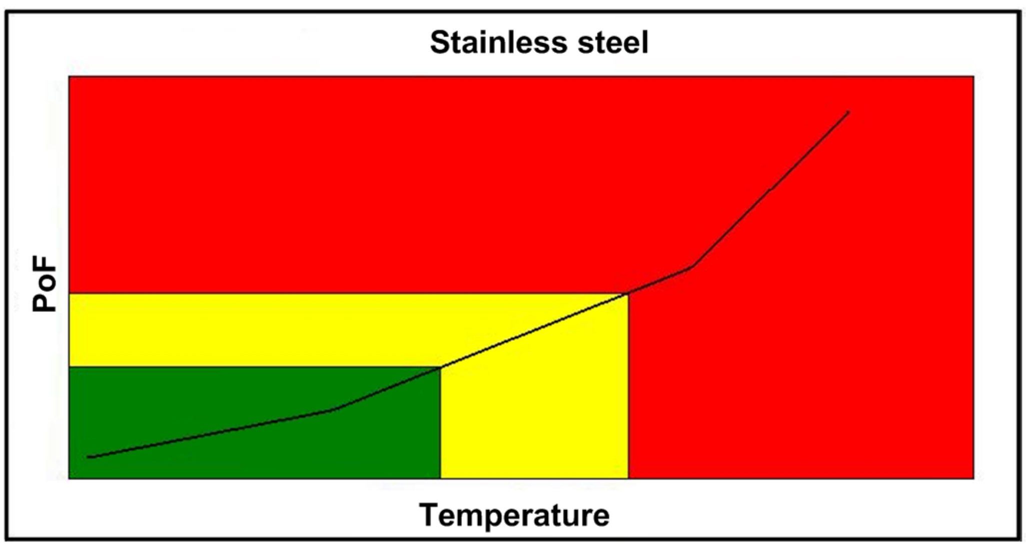

Figure 3.19 Example of acceptance limits for the susceptibility model

Figures 3.18 and 3.19 shows the condition of the equipment with respect to degradation. The colour code shows the condition using the traffic light principle: green – satisfactory, yellow – moderate, and red – critical. These conditions will be based on degradation rate or PoF, depending on the model (rate or susceptibility).

The results from such calculated degradation conditions could then be shown using a Graphic User Interface (GUI). This can be thought of as how the information should be represented to the onshore engineer (OE). Higgs and Parkin (2006) wrote a paper on important things to remember when designing a GUI:

- Keep information simple – Simple overview of the system

- Structure information with respect to criticality – Critical, Moderate, Satisfactory
- Use appropriate colours – Red, Yellow, Green
- Target the intended audience – The OE of the system
- Use graphic images that are recognizable – P&ID
- Flexible – The OE can perform changes easily (e.g. change limits, include new degradation mechanisms, change process conditions, etc.)

By following the steps given by Higgs and Parkin (2006), a simple example of an overview of the system, showing degradation condition, can be made:

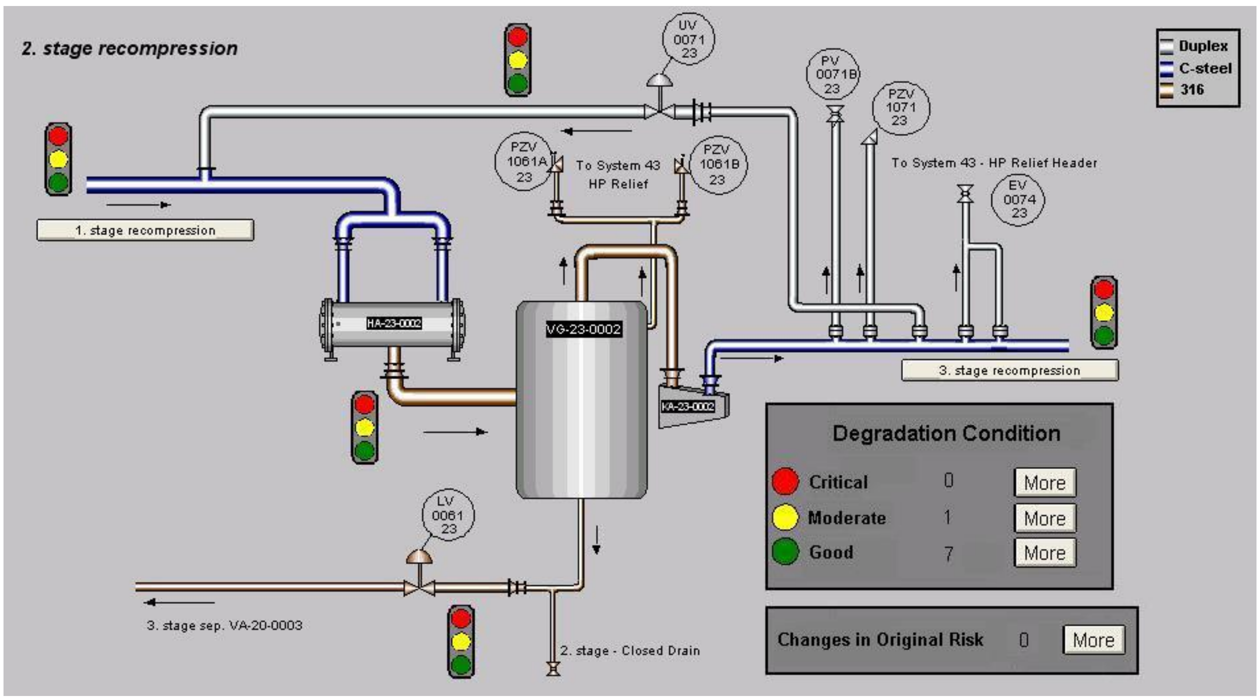

Figure 3.20 Example of an overview of the system (Adapted from DNV presentation 2, 2008)

This overview uses a traffic light on each corrosion group to show the OE the condition with respect to corrosion. The OE can then look further into corrosion groups which do not have a satisfactory degradation condition, finding the root cause of the problem, thus giving support for further decisions (ref. Chapter 3.9). This system should be flexible in the way that the OE can change limits and process condition, but also go further into each corrosion group and look at trends for each parameter. This enables the OE to discover the abnormality that causes degradation, and further provide this information to the offshore operators who can perform measures to decrease degradation. Such visualization is supported by software like ORBIT IDS (DNV), PI (OSIsoft), Maximo (IBM), SAP (Orbit, 2011; OSIsoft, 2011; Maximo Asset Management, 2011; SAP, 2011). The box in the overview window called "Changes in Original Risk" shows the number of changes to the original risk. This is found through the risk estimation (ref. Chapter 3.6) which is calculated if the change in degradation condition is at such a degree that it should be further processed (ref. Chapter 3.5d).

Data will be processed continuously, to give the OE a real-time view of the condition. Processing will be carried out at the local server, which collects and processes data. The OE can then, at any time, connect to the dedicated server and monitor the live degradation condition of the system. This will ensure that conditions can be monitored at the OE's wishes, but also enables the triggering of inspection alarms if necessary (ref. Chapter 3.7). The alarm is triggered if the results from the risk estimation (ref. Chapter 3.6) are above the acceptance criteria. So if the data is not processed, this alarm will not be triggered; thus, it should run continuously.

However, it is important that the interval that the OE monitors the condition is not longer than the averaging time period for the parameters (ref. Chapter 3.5b). This could cause the OE to overlook equipment that has had a high degradation rate. So, either the system should be monitored at a time period less or equal to the lowest averaging time period, or, the system could always show the worst degradation condition between each time the OE accesses the monitoring system.

3.5.d Further processing

Degradation conditions which will change the original risk should be further processed, and this can be done qualitatively by the OE. However, to make the system more efficient, a filter should be made where data is automatically sent for new risk estimation. Thus, moderate to critical degradation conditions should be sent for a risk estimation to ensure that the risk is not above the acceptance criteria.

The system should also be set up so the OE can send data for further processing whenever needed. Since a RBI re-analysis is done at certain intervals (e.g. every year), there must be an option where all data can be sent for a new risk estimation. Such re-analysis is done to keep the complete system up-to-date, even for the corrosion groups with a satisfactory degradation condition. This would ensure that all corrosion groups are updated with a new risk estimate, even though the changes are minimal.

More information on how to set limits is given in the chapter concerning alarm distribution and setting limits (ref. Chapter 3.7).

3.6 Risk estimation

This section shows how the risk estimation is performed when the data is approved for further processing; this is a major part of RBI analysis. Such risk estimation is done either:

- At certain intervals (e.g. every quarter, half or one year), or
- If there are changes that will update the original risk.

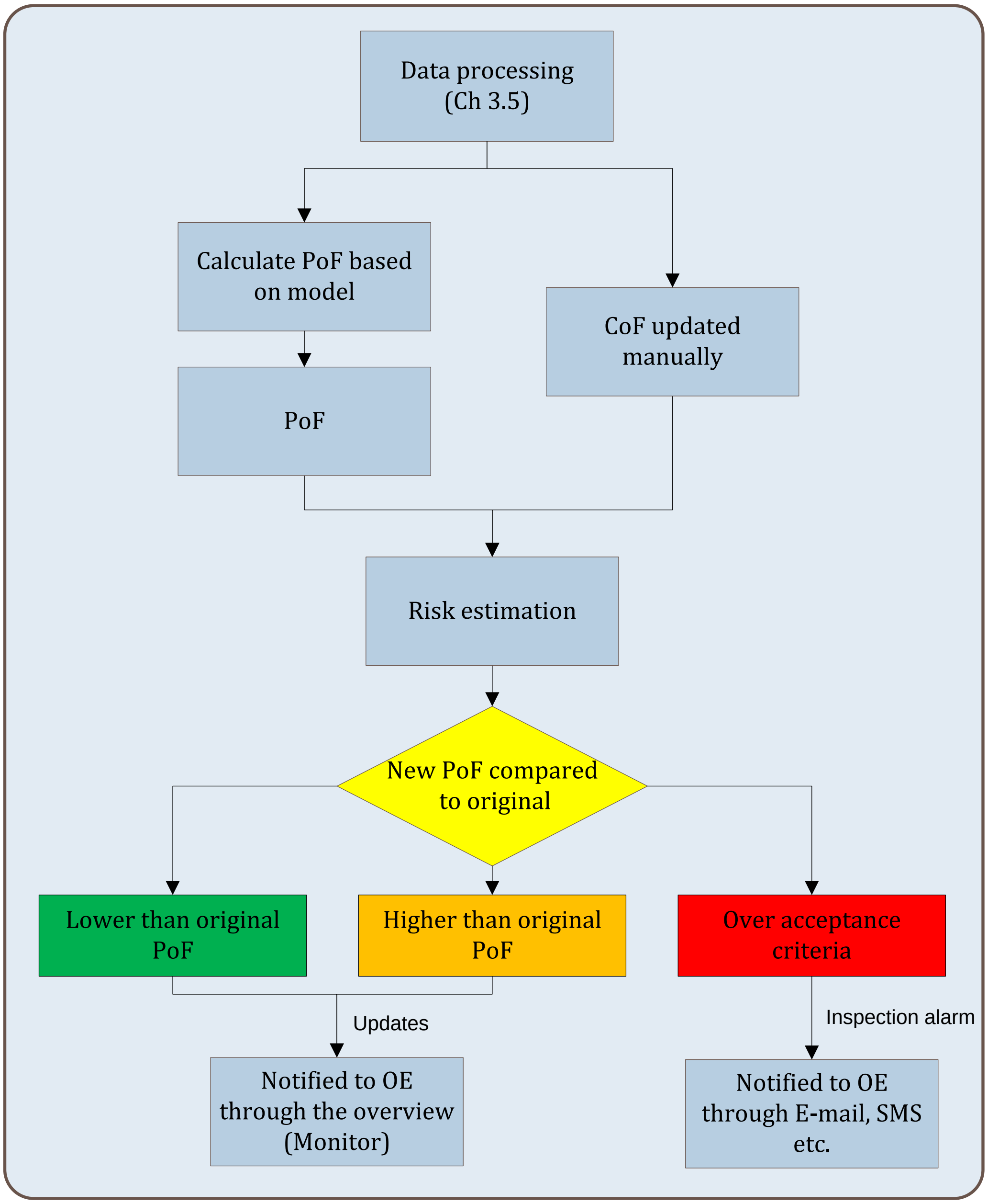

Figure 3.21 Risk estimation

DNV uses in-house developed software called ORBIT which can automatically perform risk calculations based on data. ORBIT could, therefore, be integrated with the software used to collect and process data, so values can be transferred and included in the analysis. If different software cannot be directly connected, interface software (e.g. Microsoft Excel) can work as a connection link between them (Microsoft, 2011). The only requirement would be that both programs support the same “interface” software.

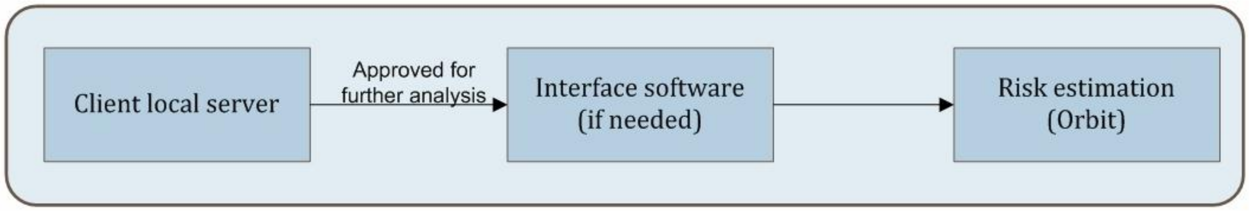

Figure 3.22 System for efficient risk estimation

However, in this chapter it will be explained how PoF is calculated for both degradation models, and how it ultimately affects the risk category. This section is based on DNV's recommended practice for RBI of static mechanical equipment (DNV, 2009).

3.6.a Calculating PoF

This chapter shows how PoF is calculated with respect to the degradation model. The PoF will change if the original parameter value has changed, and this would then ultimately affect the risk category of the equipment at hand.

Calculating PoF for the susceptibility model

The susceptibility model gives a fixed value of PoF depending on factors relating to operating conditions (Figure 3.16). Temperature is the parameter that this model focuses on since this outweighs other parameters (e.g. salt, oxygen content, pressure, flow rate, etc.). This model is thus very easy to use since just a simple conversion will give the PoF with respect to temperature. This is also already given in the data processing part, so the PoF is actually already calculated.

Calculating PoF for the rate model

Given the degradation rate for each degradation mechanism, all rates are calculated, but only the highest rate will be used to calculate PoF. This can be done since the degradation mechanisms with the highest rate, in the same corrosion group, outweigh the others. However, it is important to differentiate between internal and external, since internal degradation will not affect external degradation, and vice versa. Thus, the highest degradation rate both from external and internal degradation will be used to calculate the PoF on that particular corrosion group.

Calculating PoF based on rates is a comprehensive task, and probabilistic models like Monte Carlo (MC) simulation and First Order Reliability Method (FORM) are often used since the calculations include uncertainty (standard deviation) which are inherited from the factors that are included in the degradation mechanism (see Table 3.1). These can be included using these models through running simulations enough times (e.g. 10,000 times). For more information on calculating PoF, see DNV's recommended practice (DNV, 2009).

Corrosion rates in carbon steel piping by different categories of water		
Material Type	*Mean (mm/year)*	*Standard Deviation (mm/year)*
Raw Seawater	Flow dependent: Rates from Figure 3.14.	0.1
Seawater + Biocide/Chlorination	Flow dependent: Rates from Figure 3.14.	0.1
Seawater Low Oxygen	0.01	0.01
Seawater Low Oxygen + Biocide	0.01	0.01
Seawater Low Oxygen + Chlorination	0.01	0.01
Seawater Low Oxygen + Biocide + Chlorination	0.01	0.01
Fresh Water (Cl less than 200 ppm)	0.25	0.1
Closed Loop	0.01	0.01
Exposed Drains	Flow dependent: Rates from Figure 3.14.	0.1
Sanitary Drains	Treat as MIC. Rates from Figure 3.14.	0.1

Table 3.1 Degradation mechanism in the rate model where mean rate and standard deviation are included (DNV, 2009)

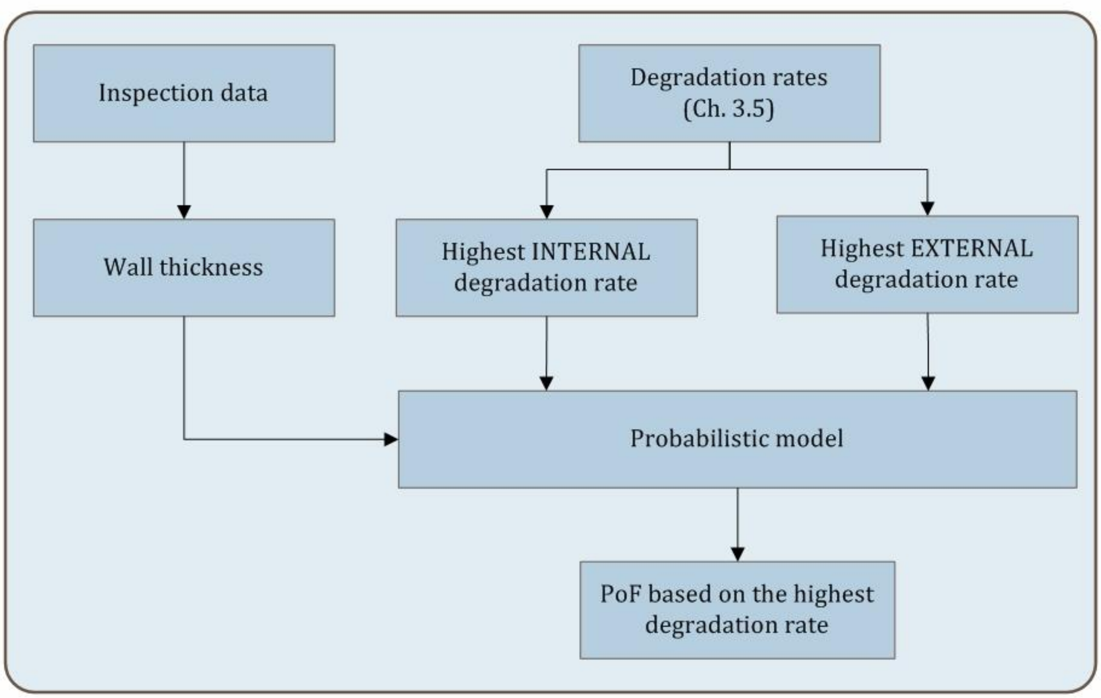

Figure 3.23 Calculating PoF for the rate model

3.6.b Estimating risk

CoF is mostly static and will not change, and will therefore be a fixed value. This CoF value will be qualitatively changed when there is a full RBI re-analysis of the complete installation. Changes that might alter the original CoF are:

- Changes in design (e.g. firewall installed, change in piping, new vessels, etc.)
- Chemicals included which can hurt personnel (e.g. acids)
- Introduction of new degradation mechanism which might cause amount of release to be greater
- Etc.

Calculation of CoF is found qualitatively where possible outcomes of incidents are discussed using fault trees and FMECA. For further information on calculating CoF, see DNV recommended practice (2009) (ref. Chapter 2.2).

When a new PoF and CoF are calculated, the risk matrix is used to find the new risk category (Figure 2.3). However, since the CoF does not change, it is possible to only look at the PoF, thus simplifying the process of finding the change in total risk. As the example in Figure 3.24 shows, PoF is the only factor which changes, thus removing the need for a full risk matrix to find actual risk.

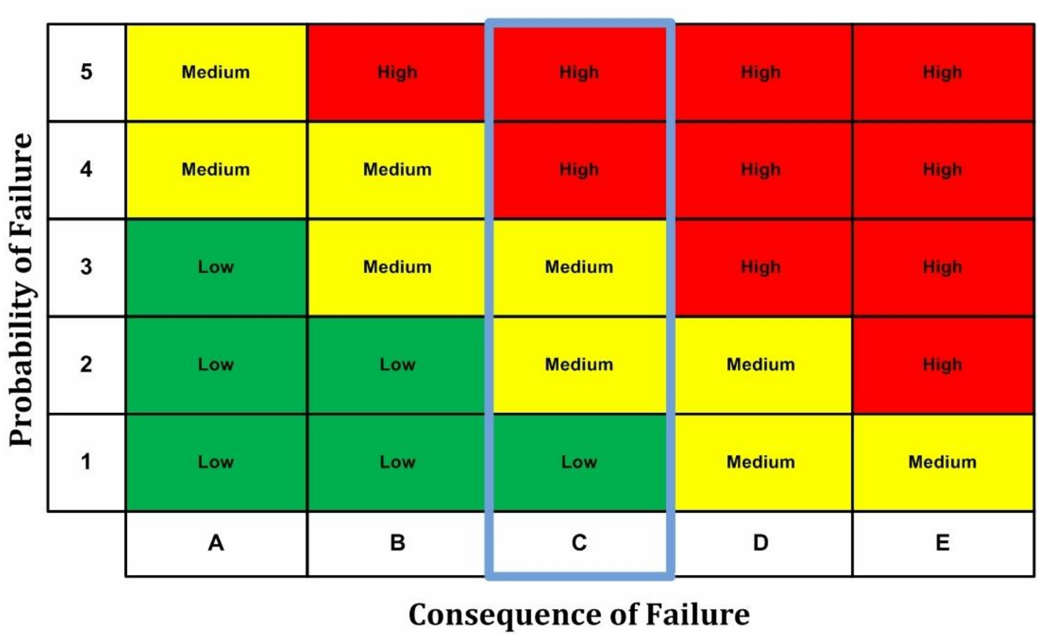

Figure 3.24 Risk-based only on PoF

There are three outcomes from updating PoF:

- Lower than original PoF
- Higher than original PoF
- Over acceptance limit – the analysis showed that the risk is over the acceptance criteria

The first two outcomes (lower and higher than original) will be shown to the OE the next time the system is monitored. This can be done by adding a box in the overview window which has to be acknowledged; an example is given in Figure 3.20 where the box called “Changes in Original Risk” is included. This window will show what changes, and how many, there are to the original risk. The OE can then look at each of these changes and find the root cause of the problem, and thereafter decide if the inspection plan should be updated (ref. Chapter 3.8). The reason why this is important will be discussed in the chapter concerning inspection planning.

If the PoF is over the acceptance limit, an inspection alarm should be triggered, and notification should be sent to the OE by e-mail, SMS, pop-up on screen, etc. This alarm notifies that an inspection should be executed to ensure safe operation and give accurate data so the OE can decide on further action (ref. Chapter 3.9). Setting such limits and distributing alarms are further discussed in the next chapter.

3.7 Alarm distribution and setting limits

This chapter will focus on how the inspection alarm is distributed and methods on how to set degradation limits, as well as alarm limits. There are different ways of setting limits, and it will depend on how the data is interpreted. Thus, some typical ways of interpreting data are considered, and how limits should be set with respect to these are explained. Figure 3.25 shows how alarms and updates should be sent depending on the criticality of the situation, thus the name alarm distribution.

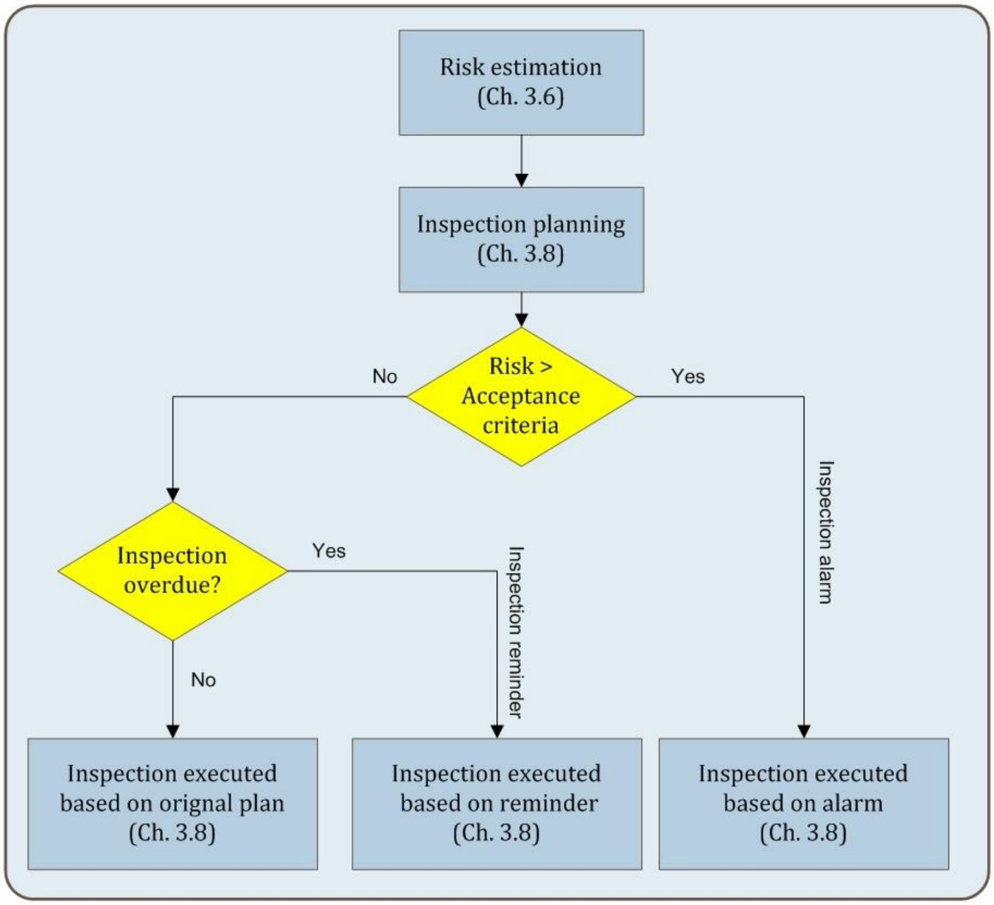

Figure 3.25 Alarm distribution

3.7.a Methods for setting limits

It can be hard to set accurate limits to give the OE the correct view of the system at hand. The limits can be viewed as threshold values, where the data indicates a potential unhealthy degradation condition. How the limits are set will depend on what they are based on, and how much knowledge there is about the data coming in. This part will focus on four methods of setting limits (Bey-Temsamani et al., 2011; Garvey, 2002):

- Expert judgment
- Statistics
- Trends
- Models

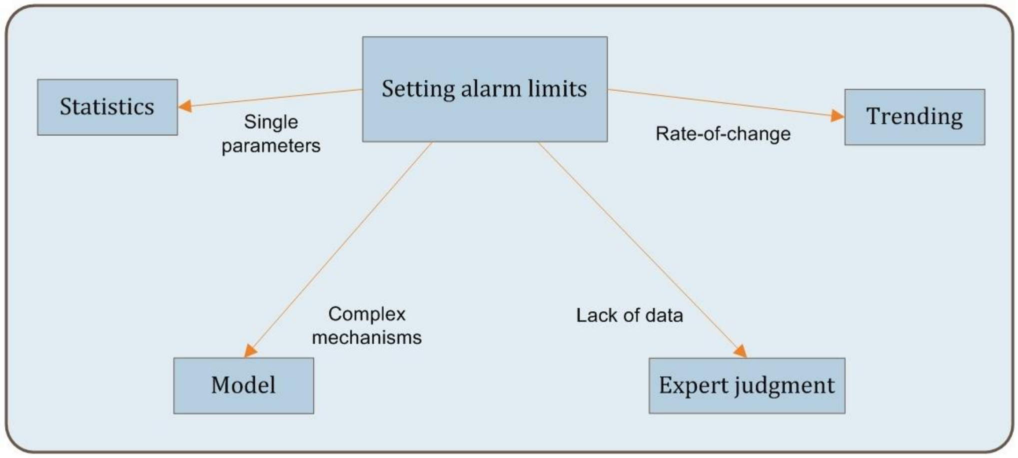

Figure 3.26 Setting limits

Expert judgment is by far the most common method of setting limits, and the method is often based on the experts' own knowledge and experience. The method is mostly used when there is a lack of information (e.g. historical data, models, etc.). A group of people with expertise in their respective field (e.g. corrosion, material, etc.) comes together to determine a limit based on their own knowledge and experience.

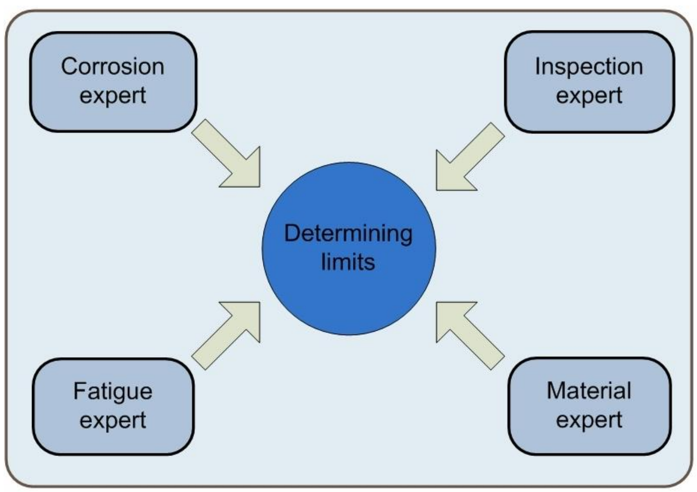

Figure 3.27 Setting limits using expert judgment

Setting alarm limits using statistics is very common. Statistical data shows the degradation condition using mean values and standard deviation for each parameter. The base line value would then be the set as the mean value, where the limits will be put at certain standard deviations. A mean value will be set for each parameter, and the limits are set with respect to degradation rate or PoF. An example is shown in Figure 3.28.

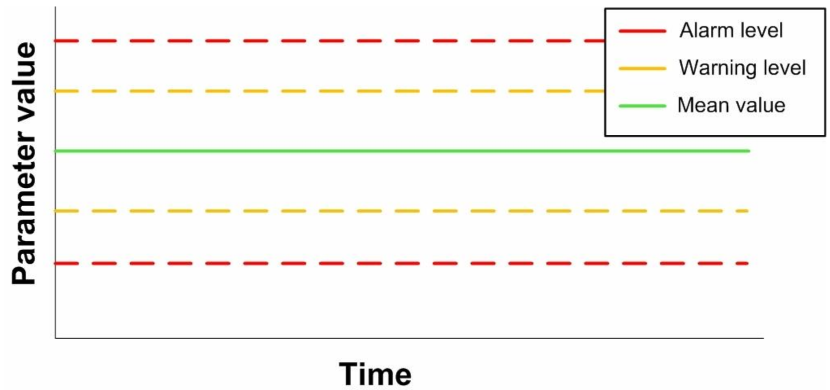

Figure 3.28 Setting limits using statistics

Setting alarms using trending is done by looking at the rate-of-change. Events often follow a certain pattern or trend (e.g. rate of corrosion, erosion, etc.), and this alarm is triggered if there is any rate-of-change. This type of alarm normally requires human interpretation where the analyst looks for a bend or a knee (ref. Figure 3.29), but it can also be done automatically by using something similar to the compression test; see Figure 3.11. This can be thought of as the use of trending with a set degradation rate, where a variance acceptance limit (as in Figure 3.28) is set to follow the preset degradation rate. Figure 3.29 shows an example of the use of trending in a qualitative way.

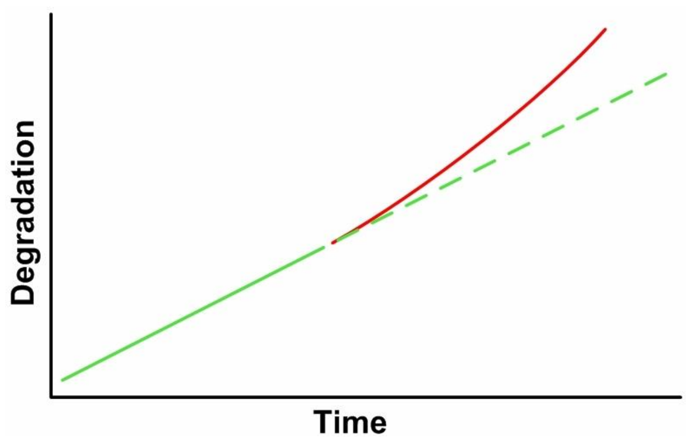

Figure 3.29 Alarm limits set using trending

The last method of setting alarms is the use of models. Models, in this case, should be used when considering more complex degradation mechanisms. Such mechanisms often include several parameters which should then be correlated to make a model, showing how they affect degradation of the condition. The model should then show how the parameters together affect degradation, and limits will then be set with respect to the correlating degradation, as shown in Figure 3.30 (ref. Figure 3.18).

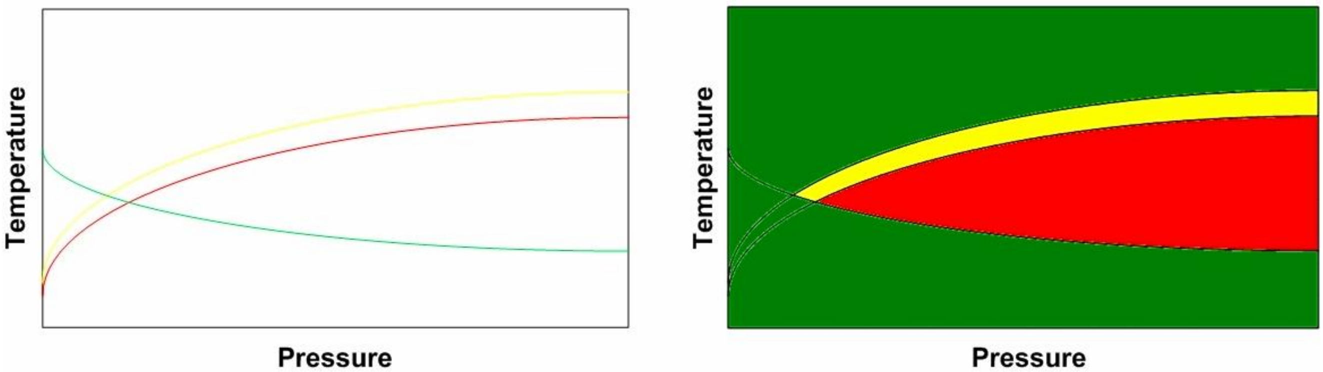

Figure 3.30 Setting degradation limits using a model based approach (Adapted from DNV presentation 2, 2008)

3.7.b Further processing

Tags with critical degradation conditions should be risk-estimated, but smaller changes could also alter the original risk. Thus, there should be a limit for how much change is allowed.

All the data is processed, and the results are given in PoF or degradation rate, for the two respective degradation models. These results should then be put up against a limit for when it should be further processed. These limits should be set with respect to the original value. The original RBI analysis is done using calculations based on set parameter values given by the offshore operator. But these values might change, thus changing the calculations for degradation condition, and ultimately the risk. Setting a limit for how much the condition can change should therefore be done.

All methods stated earlier can be used to set a limit, but some suit certain degradation models better than others. The statistical method will be used for many of the degradation mechanisms in the susceptibility model since these mostly depend on temperature. The rate model often depends on several parameters, so the model method should be preferred. Trending can also be used for the rate model where the limit is set to a certain degradation rate, and if this rate changes over a certain limit the data should be further processed.

In addition, changes do not necessarily have to be negative with respect to degradation. If the temperature becomes lower over time it will also alter the original risk. Thus, there has to be a limit "both ways", as shown in Figure 3.28, by using variance (e.g. ± 5 % change, etc.).

3.7.c Inspection reminder

An inspection reminder is triggered if a planned inspection is overdue. This will thus be triggered from the inspection plan (ref. Chapter 3.8) if inspections are not done in time. Such alarms might also be triggered when the OE updates the inspection plan with the new PoF. Some inspections then become overdue because of the change in risk; thus, also the change in the next time-to-inspect.

3.7.d Inspection alarm

The inspection alarm is there to notify the OE that the condition is at a critical level, and an inspection should be carried out immediately to ensure that production can continue. The alarm is triggered if the PoF is above the pre-defined acceptance criterion. This acceptance criterion is set by finding the lowest PoF which still results in safe operation. Standards, governmental requirements, as well as the offshore operator's and the OE's own requirements are used for setting an appropriate acceptance limit.

Since the system is set up in the way that it might not be continuously monitored, notifications should be sent to the OE if an inspection alarm is triggered. Since the local server will continuously process data and perform risk estimation (if parameters have changed), the alarm will be triggered at the right time. Ways of notifying the client can be through e-mail, sms, or simple pop-ups on the client's screen, triggered by the local server. These notifications should be made in a way that ensures that it gets the OE's attention.

3.7.e Changing limits and operation conditions
As mentioned earlier, the GUI system should be flexible in the way that the OE can easily change limits and operational conditions if necessary. Using the gathered information to change the system will be further discussed in the chapter concerning decision support.

3.8 Inspection planning and execution

This chapter will discuss how inspection plans should be updated, and how the inspections should be executed based on updates and alarms. In addition, it will show how the OE should perform a quality check of the results and verify that the calculated condition is correct. The chapter is based on DNV's recommended practice (DNV, 2009).

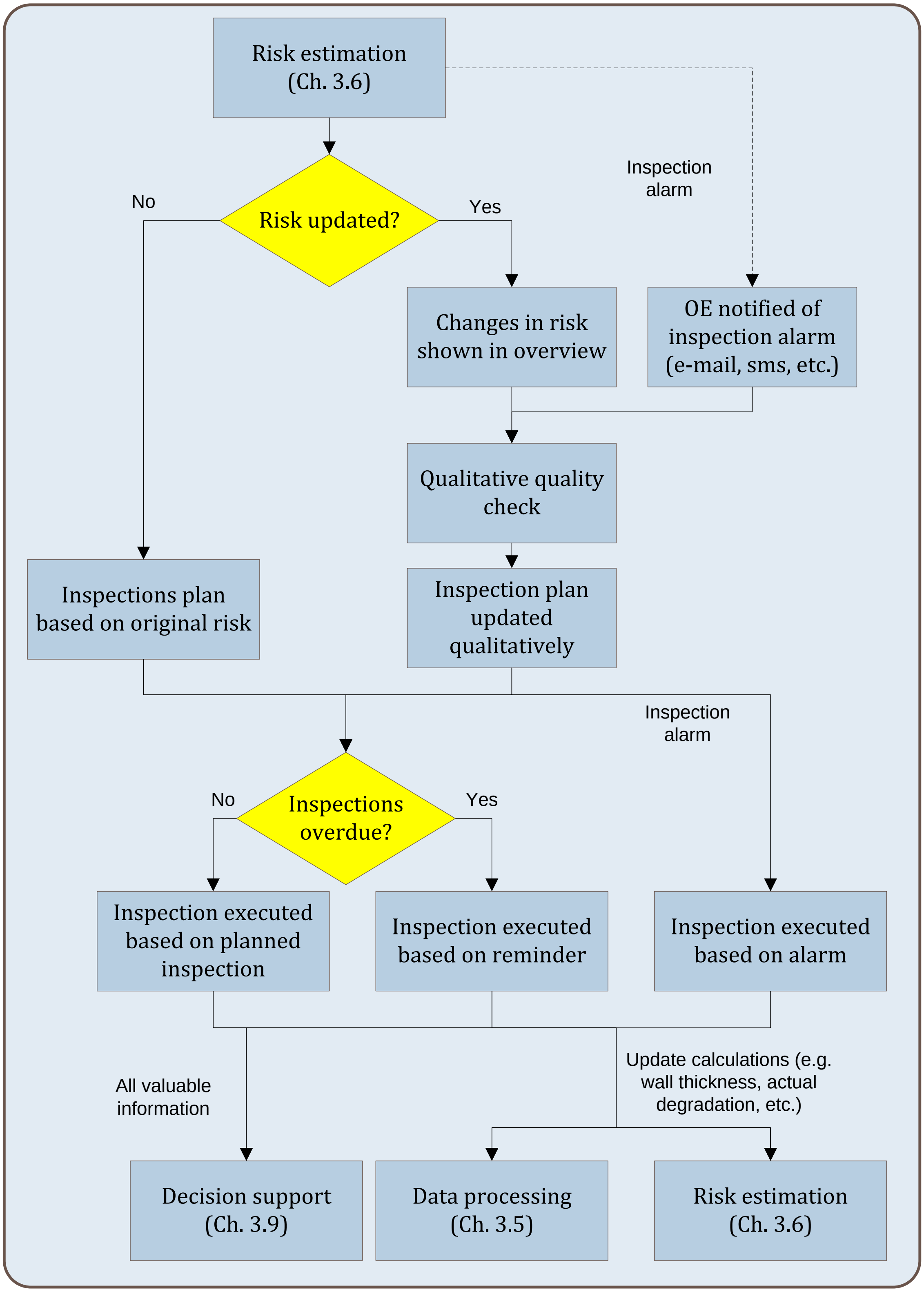

Figure 3.31 Inspection planning and execution

3.8.a Quality check of data and results

This section presents how to quality check data and ensure monitoring effectiveness. This part is based on a section of a report made by RIMAP on inspection and monitoring effectiveness (RIMAP, 2003).

Data could include errors which means that it should be checked to ensure that the results are correct. Inspections done manually (NDT) are performed by using the best technique for finding the required information; thus, the results will be the "correct" values. However, when we think of the continuous monitoring and processing of parameters, there could be errors in the data. Examples:

- Faulty sensors
- Corruption of signal (noise)
- Error in calculation
- Missing data
- etc.

When the OE gets updates of changes to the original risk, it is important to ensure that the results are correct. Firstly, the OE should find out which parameter causes the change in risk, and thereby determine if the results are true. Such a quality check is important to ensure that no faulty data is included in the inspection plan, and it should be done qualitatively by the OE.

One way of assuring correct results is by using the inspection results to see if the calculated degradation relates to the inspected degradation. This is done by comparing the calculated degradation with the inspected results, and assuring that it is higher or equal. If this is not true there could be an error in the calculation (in the equation itself or in missing data) or the sensor (faulty sensor or corruption of signal). Equation 1 shows the effectiveness of the monitoring process should be equal or above one, where D_{real} is the actual value (e.g. wall thickness, degradation, etc.), while $D_{Monitor}$ is the measured value (RIMAP, 2003). Equation 2 shows that inspection results should be less or equal to the monitored value, this would also work as a safety buffer since it would be a conservative value (better to be safe than sorry) (RIMAP, 2003).

$$\mathrm{E_{Monitor}} = \frac{\mathrm{D_{Real}}}{\mathrm{D_{Monitor}}} \rightarrow \mathrm{E_{Monitor}} \leq 1 \tag{1}$$

$$\mathrm{D_{Inspection}} \leq D_{Monitor} \tag{2}$$

Repeatability is another way for the OE to quality check data, and it is very effective when considering a continuous flow of new data. By looking at the data over a long period and finding the repeatability (e.g. pattern), a fluctuation that does not make sense can easily be discovered. This could then mean that a sensor is faulty, there is corruption of the signal or lack of data.

A full quality check of the system should also be done at certain time intervals to ensure that the calculated results are correct. Since the condition management system will be automatic until the update of the inspection plan, the actual results might be worse, or better, than the calculated results show. For example, if the nominal wall thickness was not updated with the new inspection results, this could cause the PoF to be higher or lower than it was supposed to be. Such mistakes are important since they could cause equipment to be overlooked. Thus, the OE should look into each corrosion group at a time and look for errors in the system as well.

3.8.b Inspection planning

The inspection plan made for an offshore platform will be based on the risk estimation, and since the risk changes with respect to parameters, the inspection plan will change as well. The condition management system is created to make the inspection planning as accurate as possible, and to ensure that inspections are done at the right time, and in a correct manner. Using the collected information from the previous steps (e.g. data, calculations, inspection results, etc.) as well as his/her own knowledge, the OE should be able to plan inspections so they are executed at the right time, and in the right way.

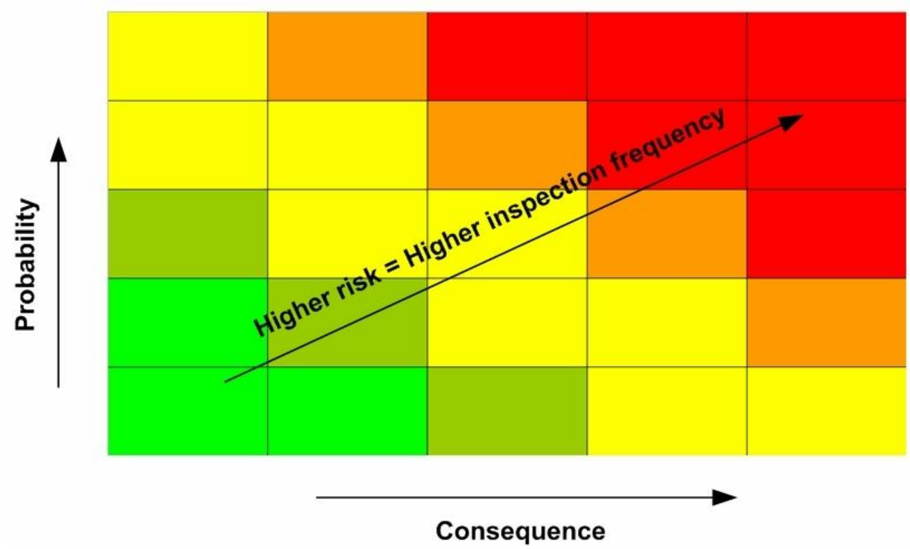

Figure 3.32 Higher risk = Higher inspection frequency

Originally, inspection plans were updated at a certain interval (e.g. every one to three years), based only on inspection results and engineering judgement. With the condition management system, the inspection plan will be updated when there are changes to the original risk. The OE will be notified of changes in risk, see Figure 3.20, and will then qualitatively assess each of these. Firstly, a quality check is performed to verify that the results are true, before the OE uses the new results to see how much this will alter the original inspection plan.

The inspection should be updated qualitatively since it does not only include when to inspect, but also where to inspect, what technique to use, what to look for, and what to report (ref. Chapter 2.2). Updates to the inspection plan will be based on processed data, but also a qualitative assessment of pictures/videos from inspections as well as knowledge based on experience and historical data. Thus, the inspection plan should be assessed and updated qualitatively by the OE.

When to inspect is set by finding how much time it will take before the PoF reaches the acceptance limit. For the rate model, this can be calculated based on wall thickness (t_0), confidence in results (a), mean damage rate (d_{mean}) and limit for wall thickness ($t_{release}$) (DNV, 2009):

$$Time\ to\ PoF_{Limit} = a\frac{t_o - t_{release}}{d_{mean}} \tag{3}$$

However, for the susceptibility model, it must be set qualitatively with respect to the parameter which affects degradation in addition to the confidence of the results given (DNV, 2009).

Since the OE will get information about which degradation mechanisms are initiated, it is easier to find out where, how, and what to look for. For example, if erosion has occurred, the inspection should be done where the flow changes direction (e.g. choke valves, turning pipes, etc.) since erosion tends to appear at such "worst case" spots. The techniques that can be used are ultrasonic testing or radiographic testing since these are adequate for measuring wall thickness. What to report will again be based on the degradation mechanism, and in this case wall thickness should be reported. For more information regarding inspection planning, see DNV's recommended practice (DNV, 2009).

All changes in risk must be qualitatively assessed before the inspection plan is updated. Even if there is an inspection alarm, a qualitative assessment of the situation should be done, including a quality check. The only difference with an inspection alarm is that it is notified directly to the OE from the risk estimation, and the inspection should be planned and executed as soon as possible since the PoF is close to unsafe operation.

The inspection plan for the complete installation should also be updated at the original interval (e.g. every two to four years). This update will go through each corrosion group and update the inspection plan based on the collected and processed information (e.g. process data, inspection data, sampled data, design changes, etc.) since the last interval.

3.8.c Inspection Execution

Inspections are executed using the most appropriate methods available. DNV's recommended practice lists the most common inspection methods: visual inspection, thermography, radiographic testing, eddy current, etc. The method used is based on the degradation mechanism, whether it is internal or external, and what the inspector is looking for (e.g. corrosion, erosion, etc.) (DNV, 2009).

Inspections will be executed based on the inspection plan, but there are three levels of inspection priority: inspection alarm, inspection reminder and planned inspections. Inspection alarms are of course most critical, while the reminders should be always be done before the original planned inspections.

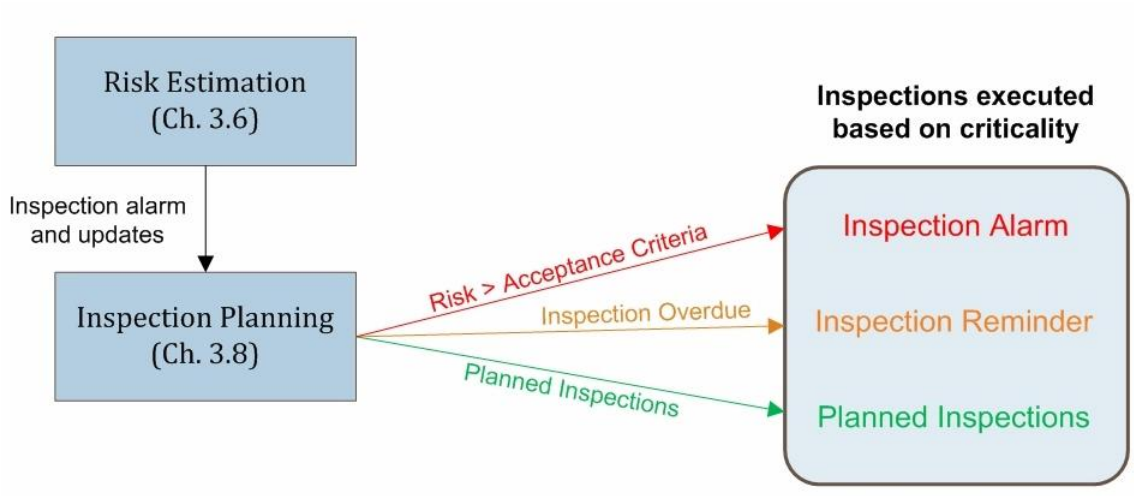

Figure 3.33 Inspections executed based on criticality

Inspection alarms have the highest priority since the risk estimation showed that the risk was above the acceptance criteria. Inspections that are based on such alarms are executed to ensure that it is safe to continue operation, and that the estimated risks were true.

Firstly, the inspector should inspect the respective equipment and find out whether the conditions stated in the analysis are true. The results from these inspections would then either support the results, or reject them. Secondly, if the results show that the conditions are not true, measures have to be taken to find out why the results were wrong. However, if they are true, decisions have to be made about what to do next (e.g. shut down production, modify equipment, change process conditions, etc.) (ref. Chapter 3.9).

Inspections based on reminders will be performed before planned inspections since they are overdue, and thus have a higher priority since the risk is higher. These inspections are carried out to ensure that conditions are at a satisfactory level and to update the risk estimation among other calculations (e.g. degradation rate, etc.) with actual, and correct, information (e.g. actual wall thickness, actual corrosion, etc.). Inspection results will also be included in the quality check of the process data where inspection data is used to evaluate the calculations made (ref. Chapter 3.8a).

The inspection report is sent from the inspector to the OE, who then uploads this on the local server. The OE would then manually include the data (e.g. wall thickness) into the appropriate models and calculations (ref. Chapter 3.5). Inspection results should be marked with an ID tag, thereby simplifying the job of including results in the correct corrosion group. The full inspection report will also include pictures, sometimes video as well, from the inspection, giving the OE better decision support.

3.9 Decision support

Decision support is where information and data from the previous steps are used to aid the OEs of the system in taking proper decisions regarding inspection planning and other enquiries. The OE has two main sources as support in the decision-making process: knowledge and information. Knowledge is what the OE has gained through experience in such field of work, while information is what the condition management is supposed to give.

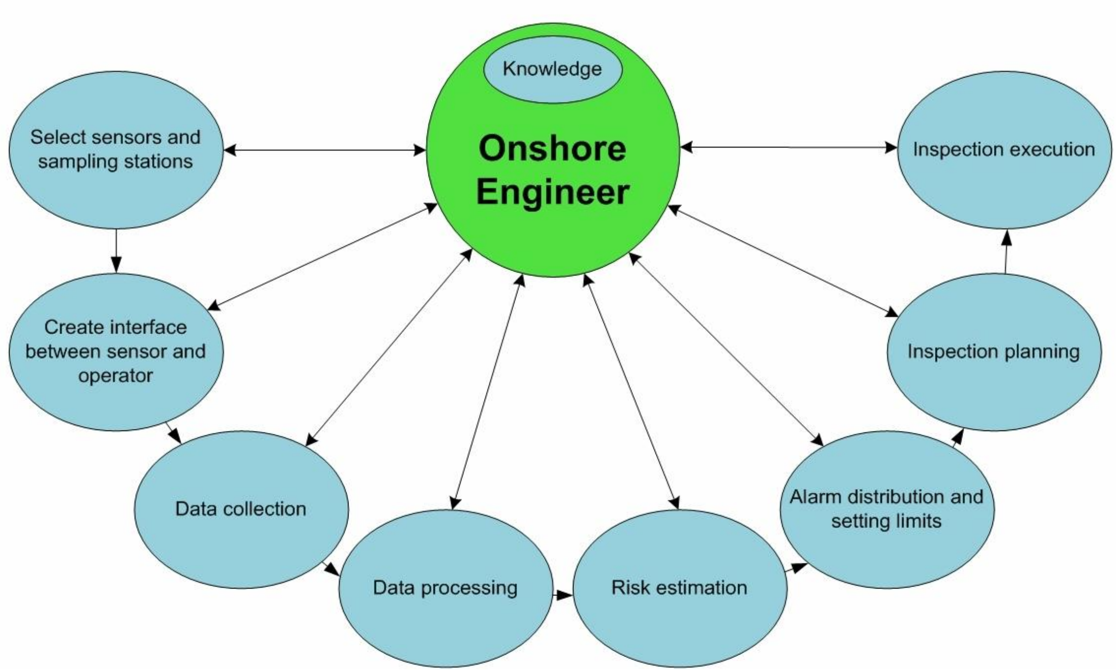

Figure 3.34 Decision support

Figure 3.34 is a simplified model showing how decision support is used in the condition management system. The OE is able to gather information from anywhere in the system as support in decisions that have to be made. This system is designed to make the inspection plan dynamic (ref. Chapter 3.8), and ensure that inspections are carried out at the right time. However, the OE can also use the gathered information to support other decisions, including future design, modifications or changes within the system itself.

Design and modifications that are going to be performed on the installation can use historical data from this system, giving the designers information on how to avoid high degradation. The OE will also continuously evaluate the system itself to make it more effective and accurate, for example including more ID tags, changing limits, changing process conditions, changing degradation calculations, including degradation mechanisms, etc. Limits regarding further processing and the time period for averaging of parameters should be assessed at intervals to make the system as accurate as possible.

Support is also important regarding another part that the OE has to decide on: the inspection alarm. When the OE is notified of such an alarm, an inspection is planned and executed as soon as possible. The results from this inspection, together with other information (calculations, trends, etc.), will give the OE a better ground to base a decision on, regarding shutting down (very high risk), performing modifications (measures to lower PoF), or continuing production (results better than expected).

However, the OE of the condition management system is not the only one that will benefit from this support system. The inspector executes inspections based on inspection plans given by the OE onshore. However, the inspector should also have the possibility of utilizing the system to make the inspection as accurate as possible. The inspection plan would include everything concerning where, how and when, but no information regarding last inspection results. The results from the last inspection would give the inspector a simple quality check of his/her own results, since the wall has to be thinner than (or equal to) last time. Estimations (degradation calculations) will in addition give the inspector an indication of what the results (e.g. wall thickness, corrosion) are supposed to be. However, estimations should not be followed blindly since inspection results are used as a quality check for these estimations (ref. Chapter 3.8).

3.10 The condition management system

The previous chapters presented the different processes in the condition management system, and gave guidance as to how each of them should be solved. This chapter will explain Figure 3.2 and show how the system can be divided into three main parts: setup, condition monitoring and risk-based inspection.

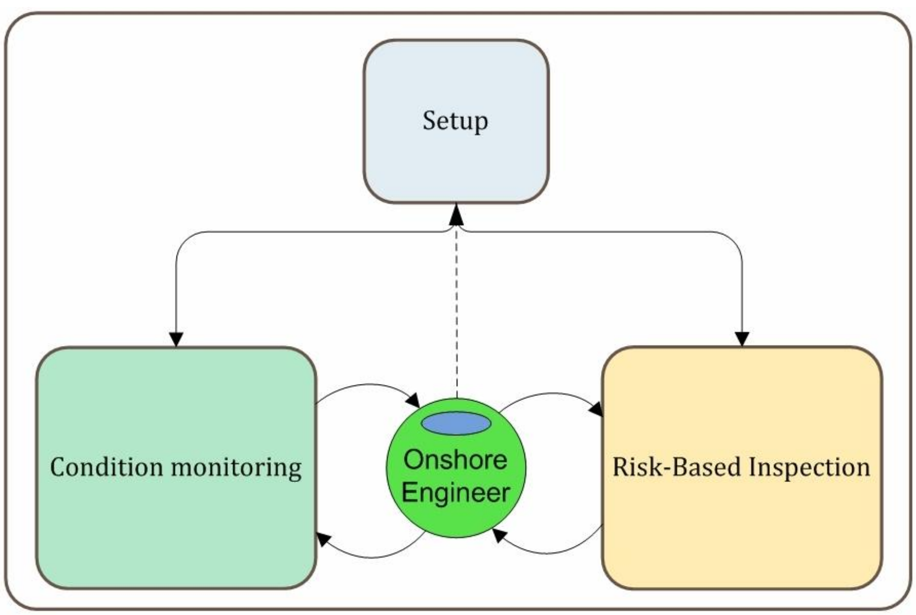

Figure 3.35 The three main parts of the condition management system (Ref. Figure 3.2)

Setup is the part where all the ground work for setting up such a system is done. This part ranges from finding damage mechanisms to how to connect the sensor to the computer. When this part is done, it would not need to be updated very often. However, changes in design, process conditions or other modifications would require changes in what sensors/sampling stations use. This is already thought of since the system is so flexible that a simple search for the correct sensor ID tag would download wanted information immediately.

Condition monitoring focuses on continuous collection and processing of data. This part is what makes the condition management system dynamic by always keeping the OE up-to-date on changes in the process. Since degradation is slow, averaging filters are included to avoid that the OE is updated on all changes (e.g. spikes in parameter data), and just the impending initiation of degradation. This ensures an efficient system where the OE can easily monitor degradation condition at all times.

The risk-based inspection part focuses on the inspection planning and execution, and the OE is of course included. The OE gathers all accessible information and uses this as support regarding inspection planning, as well as in other decisions that have to be made (e.g. system design, modifications to installation, etc.). The OE would get indications (e.g. traffic light, risk changes, etc.) of bad degradation when monitoring the system, while notifications (e.g. inspection alarms) would arise if the risk estimation is above the acceptance criteria. This is the most automatic system that can be made since many of the decisions regarding inspection planning cannot be made quantitatively.

CHAPTER 4
Discussion

This thesis presents a system where the inspection planning is made dynamic through the use of live process data. The model is based on the framework, but some parts, like the risk estimation, have been made automatic. Besides that, the model from this thesis does not use the full loop as the framework does, but instead divides the system into two loops: condition monitoring and risk-based inspection. The first loop is automatic and continuous, making it possible for the OE to get a live view of degradation conditions at all times, and also to be notified when it is not monitored qualitatively through inspection alarms. The second loop is also continuous since inspections are performed when planned, but the loop itself is updated by the OE.

A challenge with this task was to make it as dynamic as possible, through making it fully automatic. This can be done through making limits/filters wherever a decision has to be made. However, after careful consideration, the result is that this will not work when it comes to inspection planning. The decisions that have to be made in this phase need a qualitative view which computers cannot give. In addition, a qualitative check of the data should be performed since there might be errors that the filters in data collection did not detect, and to ensure that the inspection plan updates are correct before being implemented.

Other challenges with the proposed framework are to set the limits/filters for the decisions that are going to be automatic. This would be time-consuming work where each parameter has to be evaluated with respect to the degradation rate and model. Challenging limits/filters that have to be made are:

- Filter for averaging parameter data
- Limits for showing degradation condition (overview)
- Limits for the data to be further processed (risk estimated)

However, if these limits/filters are made through assessing each degradation mechanism in detail, an applicable limit can be determined. This would need expertise in the field (e.g. engineers within the fields of degradation, inspection, material, process, etc.) that would thoroughly assess each parameter of their respective degradation mechanism.

The last discussion is regarding inspection results, and making it possible for the inspector to automatically include results (e.g. wall thickness, degradation, etc.) into the system, thus removing the manual input by the OE. However, since such inspection results can include pictures and videos, it is better that an expert in degradation assesses all information before including the new results. This would ensure that the results are quality checked and correct before they are included. In addition, inspections cannot always be executed at the exact hot-spot required (e.g. poor access), which would mean that the results might not be correct, and should therefore be assessed by the OE.

CHAPTER 5
Conclusion

This thesis presents a study carried out to develop a procedure for how to integrate live process data to make the RBI analysis dynamic. The procedure intends to show how the live data can be collected and processed to effectively give the OE the live condition regarding degradation of the installation. It further shows how this information could be included in the planning of inspections, making the RBI analysis dynamic.

The proposed model uses steps from an earlier framework as a fundament, and gives guidance to how each of the processes should be carried out to make the system as effective and accurate as possible. Considerations and challenges that arose in each step are discussed, and solved using a qualitative approach. The end result is both quantitative and qualitative (semi-Q), which was done to make the model as automatic as possible, without losing the accuracy of the end result.

Live process data is continuously collected by a main server from sensors and sampling stations on the installation. Data required for assessing degradation condition is collected using unique ID tags, to avoid downloading data that are not necessary, while inspection results are received directly from the inspector. The data, including inspection results, are then processed with respect to the appropriate degradation model (Chapter 3.5). To present results efficiently, the processed data is compared to appropriate degradation limits and shown to the OE through GUI (graphic user interface) (Figure 3.20). Data with changes would automatically be risk-estimated, at which point considerable changes in risk would be notified to the OE through the GUI (changes to original risk) or e-mail (risk>acceptance criteria). The OE can then easily assess all changes in degradation and include the updated information into the inspection plan, making the RBI dynamic. In addition, the information available can also be used as decision support regarding design, modifications, calculations, etc. (Chapter 3.9).

Making the condition management system so independent and automatic means that the OE would not have to monitor the degradation condition often. The OE will only use this system when there are considerable changes to the original risk or when new inspection results are received. However, the system would still be available for the OE at all times, and everything from a detailed view of each parameter to the degradation condition of the complete system can easily be accessed. Such flexibility enables the OE to find any information required to support decisions that have to be made.

It is expected that the proposed model will be found applicable for installations that want a dynamic inspection programme based on risk. The model is based on existing technology as well as the use of existing sensors and sampling stations on the installation, which results in small modification and installation costs to create a dynamic and effective inspection programme.

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APPENDIX A

Determining PoF and CoF (DNV, 2009):

Table 4-1 Probability of failure description

Cat.	*Annual failure probability*		*Description*
	Quantitative	*Qualitative*	
5	$> 10^{-2}$	Failure expected	(1) In a small population*, one or more failures can be expected annually.
			(2) Failure has occurred several times a year in location.
4	10^{-3} to 10^{-2}	High	(1) In a large population**, one or more failures can be expected annually.
			(2) Failure has occurred several times a year in the operating company.
3	10^{-4} to 10^{-3}	Medium	(1) Several failures may occur during the life of the installation for a system comprising a small number of components.
			(2) Failure has occurred in the operating company.
2	10^{-5} to 10^{-4}	Low	(1) Several failures may occur during the life of the installation for a system comprising a large number of components.
			(2) Failure has occurred in industry.
1	$< 10^{-5}$	Negligible	(1) Failure is not expected.
			(2) Failure has not occurred in industry.

Notes:

* Small population = 20 to 50 components

** Large population = More than 50 components

Table 4-2 Consequence of failure qualitative ranking scales [ISO 2000]

Rank	*CoF Personnel Safety*	*CoF Environment*	*CoF Economic*
A	Insignificant	Insignificant	Insignificant
B	Slight/minor injury	Slight/minor effect	Slight/minor damage
C	Major injury	Local effect	Local damage
D	Single fatality	Major effect	Major damage
E	Multiple fatalities	Massive fatalities	Extensive damage

APPENDIX B

Detailed risk matrix (DNV, 2009):

PoF Ranking	PoF Description	A	B	C	D	E
5	(1) In a small population, one or more failures can be expected annually. (2) Failure has occurred several times a year in the location.	YELLOW	RED	RED	RED	RED
4	(1) In a large population, one or more failures can be expected annually. (2) Failure has occurred several times a year in operating company.	YELLOW	YELLOW	RED	RED	RED
3	(1) Several failures may occur during the life of the installation for a system comprising a small number of components. (2) Failure has occurred in the operating company.	GREEN	YELLOW	YELLOW	RED	RED
2	(1) Several failures may occur during the life of the installation for a system comprising a large number of components. (2) Failure has occurred in industry.	GREEN	GREEN	YELLOW	YELLOW	RED
1	(1) Several failures may occur during the life of the installation for a system comprising a large number of components. (2) Failure has occurred in industry.	GREEN	GREEN	GREEN	YELLOW	YELLOW
CoF Types	Safety	No Injury	Minor Injury Absence < 2 days	Major Injury Absence > 2 days	Single Fatality	Multiple Fatalities
	Envirnoment	No pollution	Minor local effect. Can be cleaned up easily.	Significant local effect. Will take more than 1 man week to remove.	Pollution has significant effect upon the surrounding ecosystem (e.g. population of birds or fish).	Pollution that can cause massive and irreparable damage to ecosystem.
	Business	No downtime or asset damage	< € 10.000 damage or downtime < one shift	< € 100.000 damage or downtime < 4 shifts	< € 1.000.000 damage or downtime < one month	< € 10.000.000 damage or downtime one year
CoF Ranking		A	B	C	D	E

APPENDIX C

High resolution P&ID (Adapted from document acquired from private communication, DNV):