University of Stavanger

Faculty of Science and Technology

MASTER'S THESIS

Study program/ Specialization: **Offshore Technology /** **Industrial Asset Management**	Spring semester, 2012 Open access
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Title of thesis: **Piping integrity problem of ageing installations located on the NCS under maintenance and modification projects.**	
Credits (ECTS): **30**	
Key words: Corrosion, Stainless steel, GRE, Vibration, Maintenance and Modification, Piping system, Pipe Support, Piping Integrity Barrier, Balanced Scorecard, Information Age competition.	Pages: 68 Stavanger, 08.06.2012

Abstract

In this master thesis the author carries out the research of the process piping integrity problems on ageing offshore installations located on the NCS in the context of M&M project activity. The author describes briefly conventional M&M projects, which are being performed on platforms and piping discipline's role on them. The emphasis of this thesis work is placed on corrosion of process piping and pipe supports, so the typical corrosion forms for them in offshore environment are discussed, with more detailed description of corrosion under insulation and pipe support related corrosion as the two most severe and typical mechanisms of corrosion. The author presents material alternatives for process piping systems with different properties and degree of corrosion resistance, analyses performance of stainless steel and GRE piping materials as the most exploited on M&M offshore projects to withstand corrosion. Piping vibration problem is discussed in terms of modification impact on ageing piping systems. Through the case study from one of the ageing platforms the author raises the issue of lack of management attention to piping integrity problems. Then the author discusses piping system integrity barriers to withstand corrosion for all the stages of the piping system life cycle, where he underlines that the role the management is vital for the barriers' effectiveness. By indicating on excessive focus of senior management of M&M service provider companies on financial indicators and insufficient attention to non-financial ones, the author emphasizes the importance of utilization of proper management systems, like the Balanced Scorecard, in order to achieve balanced performance of all organization's domains. Achieving of such an organizational level ensures M&M services provider to improve rendering of services so that the effectiveness of piping system integrity barriers, carefully developed and maintained, will provide sustainable work of piping system for years. As the result the operator gets reduced OPEX of piping systems contributing to extension of economic life of the mature field.

Acknowledgement

First of all, I would like to thank my supervisor R.M. Chandima Ratnayake for priceless support and providing great inspiration over the thesis work preparation.

I am also grateful to my company supervisor and my line manager Lene Merethe Ersland from Aibel AS, my employer, for support and kind attitude.

I have a special gratitude towards my wife Natalya Lukonina, for her measureless patience and understanding over the last four years of combining regular work with studies at the UIS.

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1. Introduction

1.1. Background

The oil and gas industry operating on the NCS is gradually stepping into a new stage of development, as many of the O&G fields are coming closer to the end of their plateau phase and some fields are entering the end-tail phase of their production life (Kumar and Markeset, 2007). At this stage of O&G field development, it becomes essential to reduce the operational expenses (OPEX) or to raise the O&G production volume to extend production period and to prolong the economic lifetime at tail-end production phase. If possible, both alternatives should be explored. Production may be increased by connecting new deposits to existing production facilities or by implementing measures for enhanced O&G recovery from existing deposits (Schulte et al., 1993).However, this often not feasible. Reducing OPEX can delay the production cut-off, but can be challenging since the production facilities, equipment and machinery are often old, worn and deteriorated, and therefore may have increasing failure rates caused by inappropriate operation and maintenance. This thesis work focuses on process piping corrosion problems, which is an appropriate example of asset that demonstrates premature ageing and, in terms of technical state, situated at final, wear-out stage of bathtub curve shown on figure 1. .

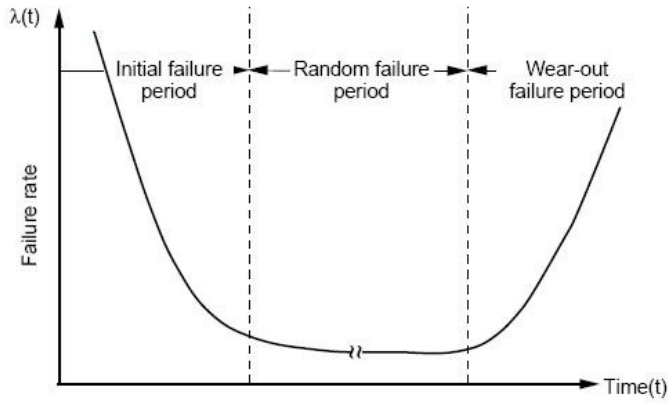

Figure 1. Bathtub curve (SDRAM Tech., 2007)

Moreover compared to modern technology, the production facilities may be ineffective and inefficient, lacking, for example, instrumentation for modern control and condition monitoring. Figure 2 depicts the potential profits and extension of the production period based on improving operational strategies of OPEX reduction.

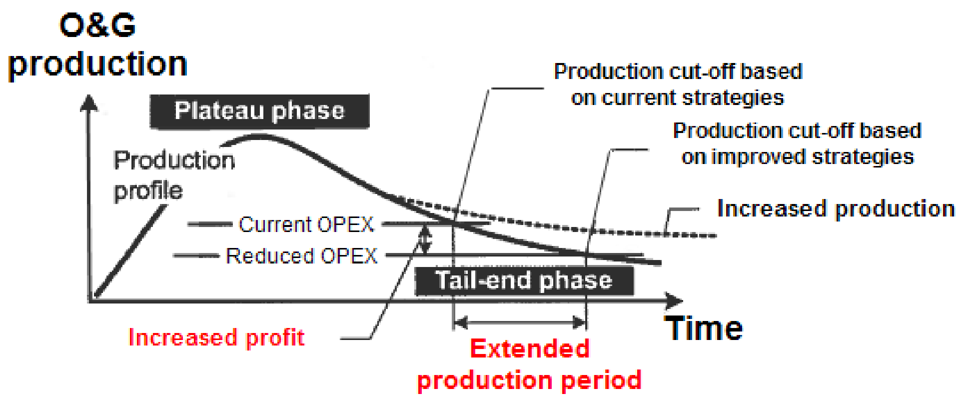

Figure 2. Extension of the production period by reducing operational and maintenance costs (Kumar and Markeset, 2007)

The two abovementioned figures give an explicit idea about the current, overall picture for the Norwegian O&G industry. Majority of offshore platforms on the NCS can be related to ageing platforms with critical failure rate of equipment and at the same time production stepped into tail-end phase where production cut-off is directly dependent on OPEX level. While overall extent of wear becomes higher and mature O&G reservoirs approaching exhaustion or lose cost-effectiveness operator companies increasingly get dependent on expertise that would be capable of dealing with these serious problems and prolong profitable life of O&G fields.

1.2. Problem description

The topic of process piping on ageing platforms on the NCS deserves serious attention. Due to continuous exposure to high temperatures and pressure, along with chemical impact of process hydrocarbons and injected additives, wear rate of process piping is higher than for other equipment and structure offshore. At the same time tough climate conditions on the NCS create favourable environment for intensive corrosion development. Because of partial ineffectiveness and obsolescence of old technical solutions and lack of maintenance, process piping on many ageing platform has been developing severe corrosion, so that piping integrity is at stake.

1.3. Objectives and scope

Serious piping integrity issues on ageing platforms on the NCS caused by detrimental effect of corrosion prompts to research this subject. Thus the objectives of this thesis work are to clarify typical patterns of corrosion development in piping systems, analyze the existing alternative methods and materials to ensure corrosion free performance, ascertain why M&M project often fail to address the piping integrity problems and define the ways to enhance effectiveness of M&M project execution.

In order to accomplish the set objectives the thesis work will look into the following:

- Description of M&M projects and piping discipline's role on such projects on ageing platforms
- Piping inherent corrosion mechanisms and methods to withstand them
- Pipe support's role in corrosion onset
- Piping material alternatives and their pros and cons
- Piping integrity barriers throughout the life cycle and M&M project management role to provide the integrity barriers
- Failure of M&M service delivery due to wrong focus of senior management
- Information age competition and new operational environment in the Norwegian O&G industry
- The Balance Scorecard utilization for proper M&M services delivery

1.4. Limitations

This thesis work explores integrity problems only in process piping belonging to top-sides of offshore platforms with nominal diameter 2" -24".

Integrity issues of process piping system on ageing problems are presented I the thesis by only corrosion and vibration problems.

The discussion of corrosion problems in the thesis work is limited to highlighting of practical things which can be interesting for engineering and technical staff.

Time limitations for preparation of this thesis work did not allow the author to examine deeper the methods of performance improvement and management methods applicable to M&M projects.

1.5. Research methods

The author's basic method of the research execution was the synthesis of personal work experience, including M&M projects pipe support engineering in conjunction with numerous offshore survey visits, and knowledge obtained during the master program study period. Work experience gave the author the key ideas about actual piping related problems of ageing platforms, while the priceless scientific knowledge presented by the university provided the author with deeper and wider insight into the problems.

Besides exploitation of work information and course literature, the author had recourse to the relevant, technical websites to obtain information related to the industrial problems raised in the thesis work.

2. Maintenance and Modification (M&M) projects on ageing platforms located on the NCS.

2.1. M&M contract description

M&M projects on production facilities on the NCS are governed by M&M contracts. M&M contracts are usually signed between an O&G operator and M&M service providing company in the form of frame agreement for a period of four to six years with optional prolongation for some years extra.

In the M&M contracts all terms and conditions (e.g. time period, amount of work, cost, hours, etc.) are defined. The payment is based on hours within a specified timeframe and budget. In the M&M contracts there are conventional and straightforward contract-client relationships. The client defines the requirements with respect to work scope and volume. Thereafter, the contractor fulfills the defined requirements at agreed time and cost. The M&M contract content can be summarized as (Kumar and Markeset, 2006):

- Scope of work
- Method for payment (hourly-based)
- Time-cost-resource focus
- Performance goals and incentives
- Requirements with respect to HSEQ (health, safety, environment and quality)
- Subcontractor’s roles and issues
- Liability issues

While the service provider renders M&M support services according to the contract scope, the customer is responsible for operation of the platforms production equipment. The operator also provides living quarters, transport and access to the site. The operator is also responsible for arrangement of safety functions for personnel, production facilities and environment over the process of service rendering.

In order to achieve objectives and requirements of all involved parties, including the customer, contractor and authorities, the service provider should develop a contract execution model, which is often called in the O&G industry a project execution model or PEM. The PEM should be developed in the beginning of the project and then followed over all contract period.

Kumar and Markeset (2006) point out that the M&M type PEM normally covers multidiscipline engineering projects where progress and quality is very much dependent on excellent internal and external activity coordination. The main objectives of PEMs are to control management, assure and maintain HSEQ, streamline the execution process, and create clear and transparent interfaces between the involved parties.

The authors indicate that a PEM describes which, when and how activities are to be performed, and functions as basis for interface between involved parties, in addition a PEM defines work orders, roles, interfaces, responsibilities, and the time-period. Besides a PEM arranges and defines checklists, tools, procedures, milestones, processes, influencing factors, acceptable quality levels. As regards key deliverables of a PEM, it involves a pre-study report, task schedule, supplier documents and drawings, system process piping and instrument diagrams (P&IDs), engineering registers, 3D models/layout, installation methods etc.

During their case study execution Kumar and Markeset (2006) interviewed implementers and executers of the M&M contracts, with the purpose of mapping industrial services processed. They stated the following:

- The focus was on their core business activities
- Cost benefit analysis is the basis for the contract
- It was not worthwhile to have all kinds of service expertise in-house. Some services can be bought in the market at competitive rates with required level of competence.

2.2. Role of piping discipline on M&M projects.

As regards M&M projects scope for piping discipline it comprises maintenance activities and modification activities. Maintenance activities assume inspections of piping equipment with the purpose of detecting wear and tear of piping systems, predominantly internal and outside corrosion and erosion of pipework and subsequent replacement of aged piping, pipe supports or insulation. Modification activities assume upgrade of piping systems in accordance with new operational requirements, like increase of production capacities, connecting of new equipment or introduction of new processes.

Both maintenance and modification tasks comprise range of standard engineering activities, such as piping design in 3D software, normally PDMS, stress calculation in CEASAR software, pipe support design in PDMS. Design of new piping is often hampered by many facts, such as lack of reliable as-built documentation at client’s data base, lack of scanning of the existing equipment in PDMS model and also very high working loads of the piping. In order to deal with these issues it needs piping discipline to collaborate with other disciplines internally on the project, with for example process, instrument and structural disciplines, and also with field engineering team on site. Besides, it is often comes up a need for contacts with client for getting any documents or information.

The final product of piping discipline work and effort on M&M project is piping and pipe support drawings for subsequent fabrication of equipment on contractor’s yard, delivery offshore, to platform. Installation of piping, insulation on piping and pipe support is normally performed by subcontracting companies, but is coordinated by M&M contractors site lead and field engineers. Installation can happen both in normal operation periods and during shut-downs, it depends on system’s criticality and possible potentially hazardous activities involved, like welding or testing of piping. Brief work flow diagram for typical piping discipline activities on M&M project is shown on the figure 3.

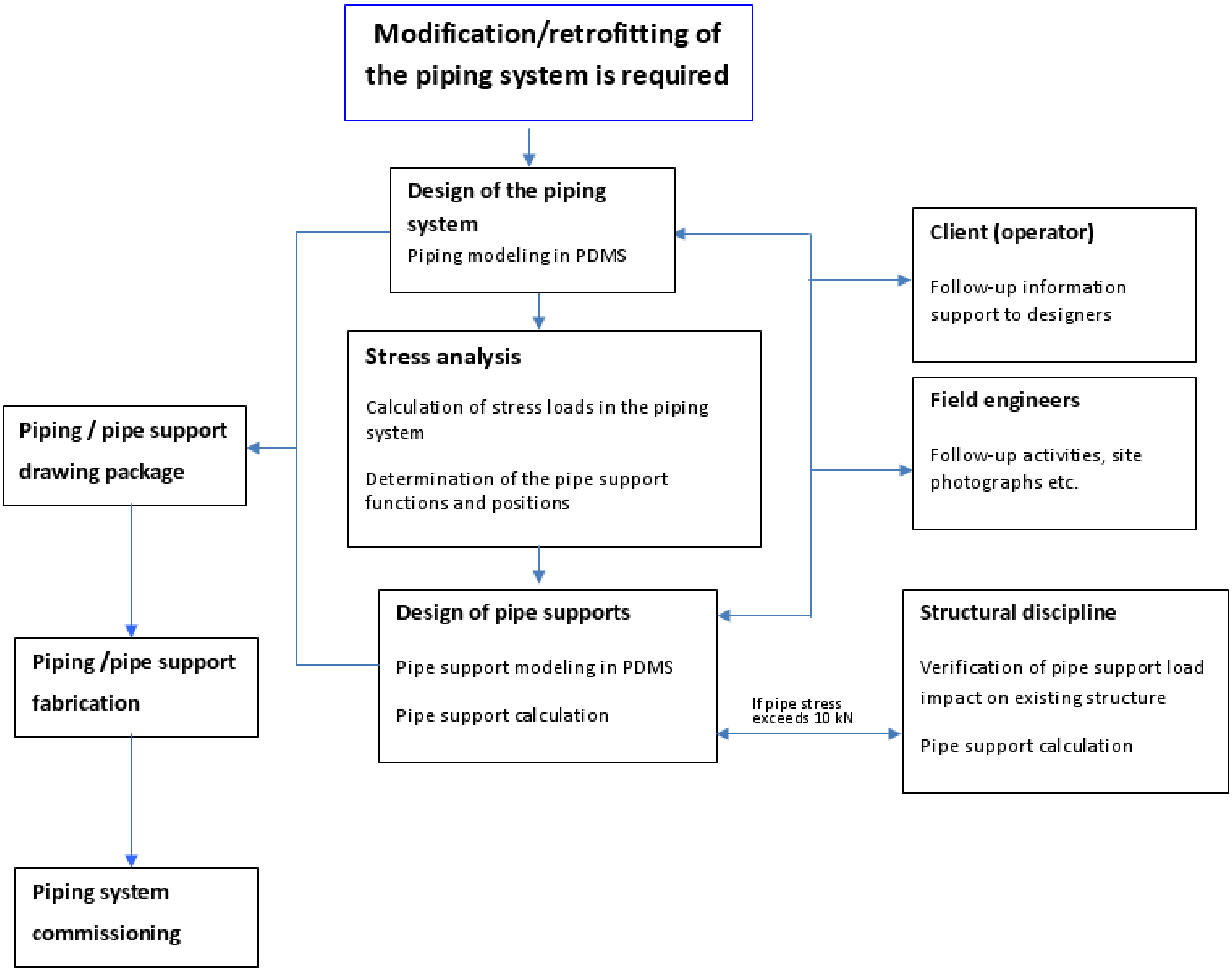

Figure. 3*. Typical work-flow for piping discipline on M&M projects*

3. Corrosion offshore

Corrosion of piping systems offshore is one of the most serious and unpleasant headaches for operators. The measures to counter this trouble cost O&G companies huge funds and make up considerable part of OPEX. Corrosion in piping systems is especially dangerous due to its frequently latent development and because of high risk of hydrocarbon leakage as a result of material damage. Operators of the NCS have great hopes for M&M service providers to eliminate or, in the worst case, mitigate corrosion threat in cost effective manner, contributing in extension of economic life and sustainable oil production further on.

In order to get insight into the causes and nature of corrosion attack offshore, it is useful to refer to international standard ISO 9223 "Corrosion of metals and alloys – Corrosivity of atmospheres - Classification". In accordance with this standard the corrosivity of marine offshore environment is ranked as highest C5 category (see table 3.1), in other words, the saline offshore atmosphere is extremely corrosive.

Category	**Corrosivity**	**Type of atmosphere**
C1	Very low	Indoor rural
C2	Low	Outdoor rural
C3	Medium	Coastal area
C4	High	Indoor aggressive chemical
C5	Very high	Marine offshore environment

Table 3.1 Corrosivity of atmosphere. (ISO 9223)

Atmospheric salinity is a parameter related with the amount of marine aerosol present in atmosphere. Saline particles in marine atmospheres accelerate metallic corrosion processes, as chlorides give rise to soluble corrosion products rather than the scarcely soluble products which are formed in rural atmospheres. Marine chlorides dissolved in the layer of moisture also considerably raise the conductivity of the electrolyte layer on the metal and tend to destroy any passivating film existing on the metallic surface. The wind, which stirs up and entrains sea water, is the force responsible for the salinity present in marine atmospheres. Oceanic air is rich in marine aerosols resulting from the evaporation of drops of sea water, mechanically transported by the wind (Morcillo, Chico, Mariaca and Otero, 1999).

As it is widely known sea territories, especially the north part of the Atlantic ocean, including the North Sea, are the areas with extremely harsh conditions and rough weather, where storms is fairly common occurrence all the year around with, in winter time storm activity tends to maximum. In other words excessive precipitation raises humidity of air offshore significantly. In summer time solar activity gives rise to evaporation from sea surface maintaining high humidity level of the air.

Aforesaid indicates that marine atmosphere is both saline and humid. Hence all offshore installations are subject to awfully adverse impact of marine atmosphere leading to corrosion or, in other words, degradation of a material through environmental interaction.

Corrosion impact on piping and pipe supports proves to be a serious threat to piping integrity.

3.1. Corrosion mechanisms typical for process piping

In addition to strong atmospheric corrosivity of marine environment causing outer corrosion, process piping offshore is exposed to a number of factors acting both alone and in combination which cause inner and outer corrosion and influence the rate of pipe corrosion. These factors include:

- pH of process fluid
- amount of oxygen in process fluid
- temperature of process fluid
- velocity/pressure of process fluid
- pipe surface damage
- surface protection damage

So offshore process piping and pipe supports develops typical corrosion forms presented below:

- **Galvanic corrosion** is a result of combination of dissimilar materials
- **Localized corrosion** (pitting and crevice corrosion) occurs due to surface defects
- **Corrosion under insulation (CUI)** is a form of localized corrosion
- **Stress corrosion cracking (SCC)** is induced by combination of high temperatureand tensile stresses
- **Microbiological induced corrosion (MIC)** is caused by microbes' activities.
- **Erosion** is induced by intensive flow rate of process fluid and solid particles contact with a pipe wall.

In this thesis work I am going to place emphasis on corrosion forms that, in my opinion, are the most severe, for process piping. These forms are presented by corrosion under insulation (CUI), galvanic corrosion and pipe supports related localized corrosion. All these three forms will be described lower.

3.2. Corrosion under insulation (CUI)

CUI is extremely severe form of localized corrosion developing in hot insulated process piping systems. CUI is the dominating corrosion mechanism for insulated piping attacking critical process systems. CUI is hardly noticeable at early stage and therefore can have severe consequences for piping system integrity. Maintenance and modification (M&M) projects engineers struggle continuously with CUI of process piping, although there is no any serious progress and improvement achieved even though more advanced insulation and jacketing materials and technologies are utilized. That is because utilization of new technologies alone is only first of the steps towards CUI elimination.

The author guesses, from his own offshore survey observations, that CUI is not as carefully treated as it should be, considering potential catastrophic consequences or at least serious problems that CUI can cause.

CUI is imperceptible since it lies under insulation material. It is costly to inspect or repair CUI problems because that usually involves inspection by radiography and ultrasonic, but in most cases requires expensive removal of insulation. Lettich (2007) in his article refers to study done by ExxonMobile Chemical where it is indicated that:

1. **Highest incidences of leaks** in the process piping are **due to CUI** but not inner process corrosion.

2. From **40 to 60 percent** of piping maintenance costs are related to CUI.

3.2.1. Onset of CUI

CUI can form if two basic elements present: high temperature and moisture. The second ingredient or water is in plenty offshore, as it was discussed earlier. Presence of oxygen is another ingredient to cause CUI in carbon steel piping and it is also plentiful offshore. Due to excessive salinity of marine atmosphere and presence of chloride ions 300 series stainless steel (SS) like L316 is subject to chloride stress corrosion type of CUI. But let's refer to factors inducing CUI onset, these are:

1. Environmental impact
2. Poor insulation design and specification
3. Installation drawbacks
4. Improper maintenance

3.2.2. Environmental impact and insulation system dynamics leading to CUI.

Environmental impact proves to be the first and the largest factor that can contribute to CUI, moreover it is the least controllable factor. Let's try to analyze all the elements of the insulation system's environment contributing to CUI.

Water, in its various forms, is the first and most important corrosion inducing element. Unless water presents, corrosion can scarcely develop itself to any real degree. Since moisture can take various forms, there are numerous ways for it to get under insulation. For offshore conditions it can be rainwater and dew falling of saturated sea air.

Operating temperature is another very important element supporting corrosion, because above 150 ^{o} C, moisture that penetrates into insulation system evaporates and then gets in touch with pipe surface and corrosion starts. Temperature interval between 0 and 150^{o}C is favorable for CUI onset in carbon steel (CS) piping system. When temperature is in interval between 60^{o} C and 150^{o} C, 300 series SS piping is exposed to CUI also. Temperature range between 90^{o} C and 115^{o} C is optimal for aggressive corrosion on both CS and 300 series SS piping because despite plenty of heat energy in the insulation system, it is not sufficient heat to efficiently evaporate and release water before it starts getting in contact with pipe surface.

Besides, water and high temperature *chemical exposure* is the final major environmental element leading to CUI. Presence of acids, acid gases such as hydrochloric acid and widespread offshore chlorine along with strong bases such as caustic are aggressive corrosion agents which cause and accelerate CUI.

Insulation system dynamics is the dynamic of the processes those occurs under the insulation and jacketing system, exterior cover of insulation. The thickness of insulation is basically designed for energy conservation or in order to maintain an outer jacketing surface temperature of 60° C to 71° C to avoid or minimize burns of personal in case of touch of the insulated surface.

Aluminum and stainless steel are two common materials used for jackets. Jackets have some type of paper or plastic corrosion barriers bonded to the inner side for prevention the jacketing from direct contact with the damp or wet insulation (Dampney, 2012) Jacketing system is supposed to be water tight, but unfortunately it is scarcely achievable due to range of adverse effects that will be discussed later, like improper design, installation, sealing and wrong insulation material choice for given service conditions. All this drawbacks prompt to apply certain type of insulation system where water penetrating into insulation can leak out. However the portion of water that fails to leak out is commonly absorbed within the insulation system in the state of water, moisture, steam or mixture of those states. Growth of pipe surface temperature above boiling point cause water contacting with a pipe or hot insulation starts boiling and steam eventually moves away from the pipe surface back to the insulation system. Cooling down below boiling point results in re-condensation of steam. This process will happen in repeated pattern as a pipe cools down and heats up.

Figure. 4. Insulated pipe (Dampney, 2012)

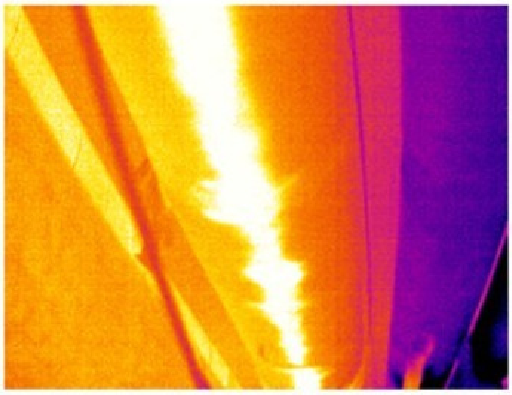

Figure. 5. Infrared Thermal -Gram of Insulated (Dampney, 2012)

An example of insulation systems dynamics constantly occurring within insulation systems is depicted on figures 4 and 5. The figure 4 is a pipe section, while the figure 5 is infrared thermal-gram of that pipe. Lower area of the pipe, colored white, represented on the figure 5 is the hottest area where hot water and steam laying in the bottom of jacketing, moreover volume collected is sufficient to come in contact with lower area of the hot pipe. Higher on the jacket there are areas represented by yellow and orange colours, these are cooler areas where temperature decreases. Insulation is drier and hence more effective here.

Dealing with environmental factors that cause CUI

Environmental impact on CUI is almost uncontrollable therefore special attention is to be paid to other factors contributing to CUI like design and specification, installation craftsmanship and maintenance of insulation system.

3.2.3. Design and specification leading to CUI

Often the original design of equipment is the start of CUI problems. Piping or manway openings for equipment that are sized too short to extend past the weather barrier of the insulation system provide an optimal leak area for water, corrosive chemicals and contaminates to get into the insulation to start corrosion (Lettich, 2007).

There are often problems with correct design and specification of protective coating for CS and 300 series SS piping which operates in the temperature condition where CUI is likely to happen. It sounds amazing, but historically, protective coating for carbon steel piping was not intended at all, since it was believed from one hand that insulation system was protective coating itself, from other hand they supposed that any water should evaporate if piping operates above 100 ^{o} C.

Failure in insulation design or specification is often caused by either using a specification without proper consideration of various factors that will exert influence on the insulation performance or due to attempts to save on insulation material cost without respect to long-term and overall operational costs especially in case of replacement.

Insulations manufacturers produce a great variety of insulation products, but nevertheless their clients on offshore M&M projects should always keep in mind that there is no single insulation material, shape, size or configuration that can provide well performance in every use. However an experienced insulation engineer is capable of making right choice of this variety of products and select cost-efficient and durable insulation system.

A suitable example of improper choice of insulation is presented on the figure 6. Here we can see a case of a delicate, all service jacketing (ASJ) specified and installed on steam, hot water piping of water treatment plant. Exposure to sun, rain and wind caused the rapid jacketing's deteriorating, soaking the insulation material and ultimately corroding the CS steel piping. That led to replacement of some hundreds meters of piping. Such an insulation type is only suitable for internal use.

Figure 6. Improper choice of jacketing (Lettich, 2007).

3.2.4. Installation craftsmanship of jacketing and weather barriers for CUI prevention.

Quality of installation has decisive effect on performance and life of insulation system. Improper or poor quality installation can significantly spoil good insulation design and specification. Especially negative influence of improper installation proves to be on the piping systems operating within CUI potential temperature range from 0^{o} C to 150 ^{o} C, having cyclic operational temperatures, or if shut down may take a place.

Due to poor installed insulation system moisture or corrosive chemicals leak into the insulation and often to the insulated pipe surface that, in turn, trigger CUI.

One of the examples of improper jacketing installation is illustrated on the figure 7. Here it is shown that final barrier to moisture intrusion, like caulking and sealants, is not installed at all.

Another example on the figure 8 represents a situation where jacket materials are installed without proper “fit and finish” that results in easy water access. Caulking and sealants cannot successfully seal gaps between jacket components exceeding 5 mm.

Another example demonstrates how improper installation of jacketing or weather barriers can spoil a proper rainshed. On figure 9 there is a vertical part of pipe where lower sections of the jacketing are installed over the top of upper section.

Figure 7. Absence of final barrier on jacketing (Lettich, 2007).

Figure 8. Improper installation of jacketing (Lettich, 2007).

Figure 9. Lower sections of the jacketing are installed over the top of upper section leading to water ingress (Lettich, 2007).

Dealing with improper insulation installation that causes CUI

To avoid CUI insulation systems must be installed strictly according to specifications. Installation team should be sufficiently trained. Follow-up is a must to ensure the job is properly done. Any problems and failures must be fixed immediately to prevent CUI development.

3.2.5. Role of maintenance in CUI prevention.

Maintenance problems can cause CUI even though the design/specification was perfectly performed along with installation craftsmanship. At the same time decent maintenance can minimize CUI risks that are able to threaten pipes integrity due to deficiency in design and installation. Insulation maintenance can be a case of too little and too late. For example there are sealant problems on the figure 10 and small holes in the weather barrier on the figure 11 which unfortunately do not get noticed until rainwater leaked into the wholes causing extensive CUI problems and possible failure.

Figure 10. Sealant problems of jacketing (Lettich, 2007).

Figure 11. Small holes in the weather barrier (Lettich, 2007).

It is noticeable that on different offshore platforms of relatively same age, belonging to one operating company, technical state and wear level of equipment including process piping can vary significantly. In authors opinion this indicates on difference in attitude of maintenance and management authorities to corrosion problems and their potential consequences.

Lettich (2005) gives an example of a chemical plant where 300 series SS piping were used in manufacturing process. Piping was insulated for heat conservation. A plant-wide insulation audit/assessment revealed extensive insulation system damage. When the maintenance engineer of that plant was asked by an inspector about any corrosion problems the answer was negative. The inspector was fairly mystified by the answer until the maintenance engineer specified that he knew about plenty of corrosion on SS equipment, but he supposes that the plant had not had any "problems" because they had not had any equipment failures due to the corrosion yet.

This example indicates on lack of maintenance authority's correct perception of corrosion threat. It is strange that personnel with such a high level of responsibility have mentality as it was illustrated in the example.

3.2.6. CUI. Area of concern on the NCS.

Recently, while reading the "Teknisk ukeblad" magazine, the author of the thesis came across an article which attracted his attention greatly. The article was called "Offshore boom raises recruitment offshore" and revealed disgusting things happening offshore. The article tells about increased recruitment of foreign workers from the Eastern Europe to satisfy huge workforce demand for offshore modifications. Poor knowledge of language proves to be a big problem and threat for safety and quality of work performed by the foreigners.

Representatives of some trade unions told the Teknisk Ukeblad that language issues offshore give reason for anxiety. And this is especially relevant for so-called ISS (insulation, scaffolding, and surface protection) indeed the ISS discipline accounts for a majority of foreign employment from the Western Europe, and problem is expected to raise further on. An anonymous employee in one of the ISS companies, a skilled offshore worker with extensive offshore experience also indicates on big language problem. He told that periodically, especially in spring, great influx of temporary foreign workforce occurs. The anonymous worker stated that during his every single offshore stay there were episodes of improperly done work due to language problem. Moreover he emphasized that foreign workers signed the work procedures without understanding what they put signature to. The employee also told that there are some injury incidents with foreign workers from time to time. But above all he was very astonished by fact that foreigners managed to get work offshore without safety course passed, since language skills is prerequisite for safety learning. In addition, the worker told about tough rotation schedule of foreigners which is different from normally accepted and consists of two weeks offshore and only one week off in between.

It is sad to hear about such things but the author is inclined to believe the anonymous worker. The author has been offshore several times in the spring periods, when piping modification activities including replacement of piping spools, pipe supports and, of course, insulation were in progress. At that periods, the number of employed workforce raised by multiples from about 200 to over 700 workers. Specifically the shut-down rush was noticeable when two-weeks' time restriction exerted significant pressure on operational pace. Platform managers often addressed to personnel and put special emphasis on safe work execution.

Indeed, working in tough work conditions and time squeezing itself can cause safety and quality troubles not to mention working under circumstances of language skills deficiency. In the authors' opinion situation is critical and problems with insulation are guaranteed. As it was described earlier in description of CUI, installation craftsmanship is crucial for impermeability and consequently effective insulation system performance. If the situation with foreign workforce stays unsolved modification activities on insulation replacement is not only useless, but it even can have opposite effect on piping and cause intensive CUI onset. Quality of insulation installation should not be at stake for the sake of speed and careful investigation to be performed in order to determine how it can happen that personnel with language problem managed to pass safety course and be employed.

3.2.7. CUI. Summary

A good specification of insulation system is not enough for acceptable performance, unfortunately. As experience shows continual follow-up is needed during the design and construction of insulation. CUI management systems are needed during operations and maintenance. Personnel must be trained carefully to develop right perception of corrosion related problems. The most important issue for CUI problem solution is management attitude, thus better understanding of the CUI problem by operators and management is a must.

3.3. Galvanic corrosion.

The low resistivity of seawater also promotes strongly galvanic corrosion. Galvanic corrosion is seen as a major concern for materials' performance in marine environment. Also SS can suffer galvanic corrosion, or it causes galvanic corrosion to other, less noble, alloys (Heselmans, 2006).

It is widely known that SS suffers from galvanic corrosion if connected to titanium. In case it is connected to CS, SS will cause galvanic corrosion of CS. In the same time, the SS parts close to the connection CS/SS will be protected against localised corrosion. In fact the CS parts act as sacrificial anode for the SS parts.

Nevertheless the figure 12, below illustrates an instance how widely known principles about combination of materials can be ignored, there we can see "advanced" modification of wire water system on one of the platform on the NCS, when CS valves have got new titanium piping around as a result of modification. Thus titanium which causes galvanic corrosion even for SS products rapidly destroys CS valves so it is evident that a failure is a matter of time in this case.

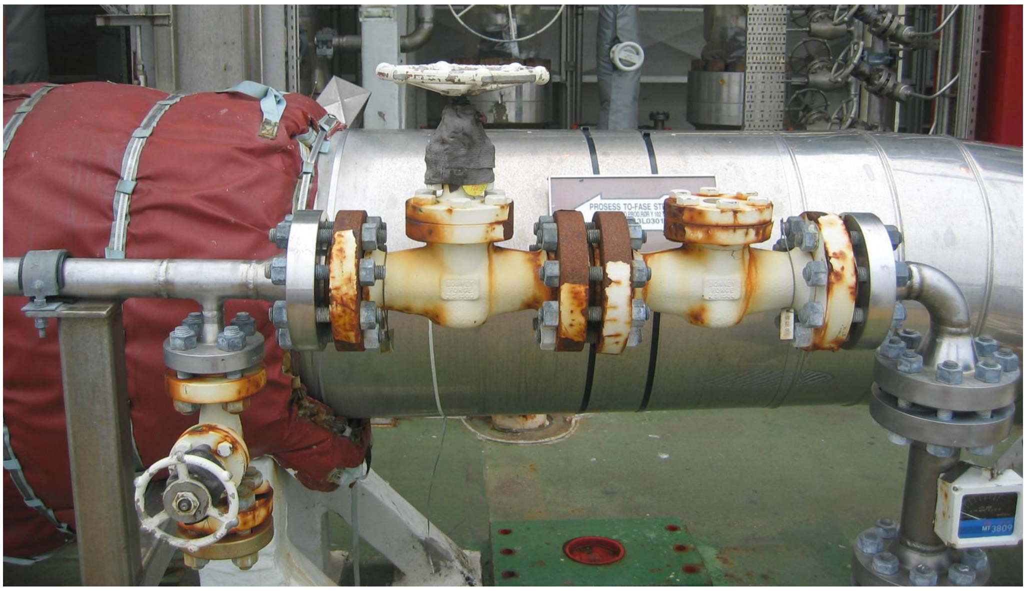

Figure 12. Fire water system offshore. Carbon steel valve on titanium pipes

It is beyond the author how such a ridiculous situation with combination of these incompatible materials could occur on a modification project where material discipline always involved in project activities. Could they make this mistake? It is very doubtful. It seems like the input provided by material engineers was not properly processed due to poor work processes and coordination on the project.

Another case shown on figure 13 proves to be a tricky one. Here there is a cast iron butterfly valve showing extreme rapid corrosion. Failure analysis performed proved that this was caused by galvanic corrosion. The valve was positioned in a GRE pipe on short distance to a huge duplex SS sea water cooler. The valve was driven by an electrical engine and both the valve and the cooler were grounded. The galvanic current passing through the ground link was measured, it was as much as amazing 340 mA.

For safety and economic reasons, the ground connection could not be changed so that the solution in that case was either choice of a SS valve, or installing a sacrificial anode in the GRE pipe. The remedy for galvanic corrosion was either arranging electrical insulation with PTFE, or cathodic protection, or both. The first solution not always gives full guarantee to a corrosion free performance and the latter solution requires design by specialists (Heselmans, 2006).

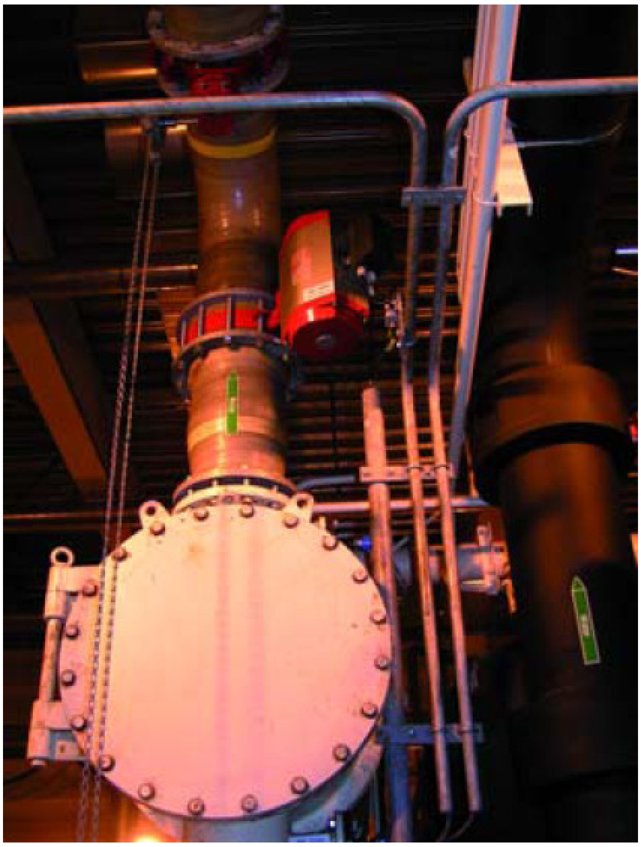

Figure 13. Position of cast-iron valve compared to duplex SS seawater cooler (Heselmans, 2006).

The example with cast-iron valve and duplex SS seawater cooler indicates on failures that are not so easy to notice, at first glance everything looks perfect and blameless. In contrast to previous case where absurdity of modification is obvious and sticks out a mile, this example shows how sophisticated the approach to addressing galvanic corrosion problems should really be. Indeed, according to popular belief galvanic corrosion is strictly associated with two materials contacting with each other with presence of water. If management approves combination of titan with CS, then I assume that attention to galvanic current passing through the ground link will scarcely be paid at all.

3.4. Role of pipe supports in corrosion damage management

3.4.1. Introduction of pipe supports

Process piping offshore is always subject to high pressure and temperature of hydrocarbon fluids circulating inside. Besides many processes of hydrocarbon treatment on offshore installation have cyclic principle, so that that regular heating up and cooling down of piping happens due to continuous start-ups and stoppages of a certain system. These temperature variations are also relevant for systems with auxiliary function. Piping systems connected to dynamic equipment, such as gas compressors and pumps, are continuously exposed to vibrations.

In order to protect piping and equipment against excessive stresses, as a result of thermal expansion and contraction of pipes, in conjunction with vibration and pressure differentials, proper supporting of the piping system is vital. Quality supporting will also protect piping against deflection related load.

A pipe support is a device used to carry pipes weight, weight of in-line equipment (e.g. valves and instruments) and process fluid and, in addition, provide restriction on excessive thermal geometry variation leading to critical exposure of piping to high stresses and subsequent material fatigue, stress corrosion cracking etc., that may cause rupture or leakage of process fluid.

There exist three types of pipe supports for pipes:

- Rigid pipe supports.
- Spring pipe supports
- Dynamics pipe supports

3.4.1.1. Rigid pipe supports

Pipe supports of this type are considered to be conventional and used in most of cases (see picture 14). These supports consist of pipe support framework, connected to the existing structure, and standard pipe support detail, like U-strap, clamp or shoe, installed on the pipe and connected to pipe support framework.

Figure 14. Rigid pipe support: U-straps detail bolted to pipe support framework

As per figure 15, pipe support functions can be classified as follows:

- Line guide (LG) function : for restriction of lateral movements of a pipe
- Line stop (LS) function: for restriction of axial movements of a pipe
- Hold down (HD) function : for restriction of upward movements of a pipe
- Rest (RS) function : serves as a pedestal for pipe
- Anchor function: combination of all above mentioned function (LG, LS, HD & RS) to restrict movements in all possible direction

In order to balanced pressure and temperature induced stresses in a piping system, proper stress analysis of a designed pipe is to be performed. Stress analysis results in identifying of pipe support locations along the pipe and certain pipe support functions of pipe supports.

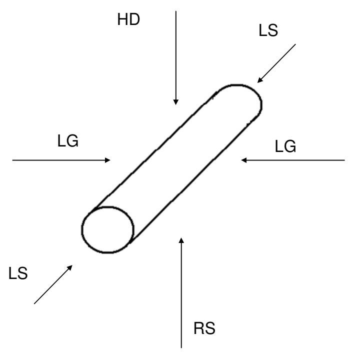

Figure 15. Pipe support functions.

3.4.1.2. Spring pipe supports

It happens that rigid pipe supports are not suitable for some operational conditions, for instance when the vertical movement of the pipe is within relatively broad interval and rigid support can excessively restrain the pipe, and consequently create large stresses in the pipe or high loadings on nozzles of connected equipment. Spring support can be a perfect solution in this case. There exist two types of spring supports: **variable** (see figure 16) and **constant** (see figure 17) spring supports.

Both types of spring supports exert a predetermined upward force on the pipe through pre-compression of coiled springs. Pre-compression force of the spring should correspond to the pipe's weight that is planned to be supported by this spring support, excessive pre-compression may cause undesirable weight loading on adjacent equipment.

The difference between variable and constant spring supports is following: when the pipe moves from the installed to the operating position the force exerted by a variable spring alters as the compression of the coiled spring is either increased or induced where as that of constant unit remains virtually unaltered (Piping-World, 2008).

Variable spring supports are preferred to constant on economic grounds. Generally variability rate at spring supports adjacent to strain sensitive equipment such as pumps, compressors and turbines is limited to 20 %, thus if a suitable variable spring support cannot be specified, a constant spring support should be used (Piping-World, 2008).

Figure 16. Variable spring support. (WorleyParsons, 2008)

Figure 17. Constant spring support (WorleyParsons, 2008)

3.4.1.3. Dynamic pipe supports

Dynamic pipe supports are intended to protect piping and sensitive plant equipment against unforeseen, rapid displacement caused by shocks. An example of dynamic pipe supports is a **mechanical snubber**, or shock absorber. A mechanical snubber (see figures 18 & 19) is a mechanical device designed to protect components from excess shock or sway caused by seismic disturbances or other transient forces. During normal operating conditions, the snubber allows for movement in tension and compression. When an impulse event occurs, the snubber becomes activated and acts as a restraint device. The device becomes rigid, absorbs the dynamic energy, and transfers it to the supporting structure (Wikipedia, 2011).

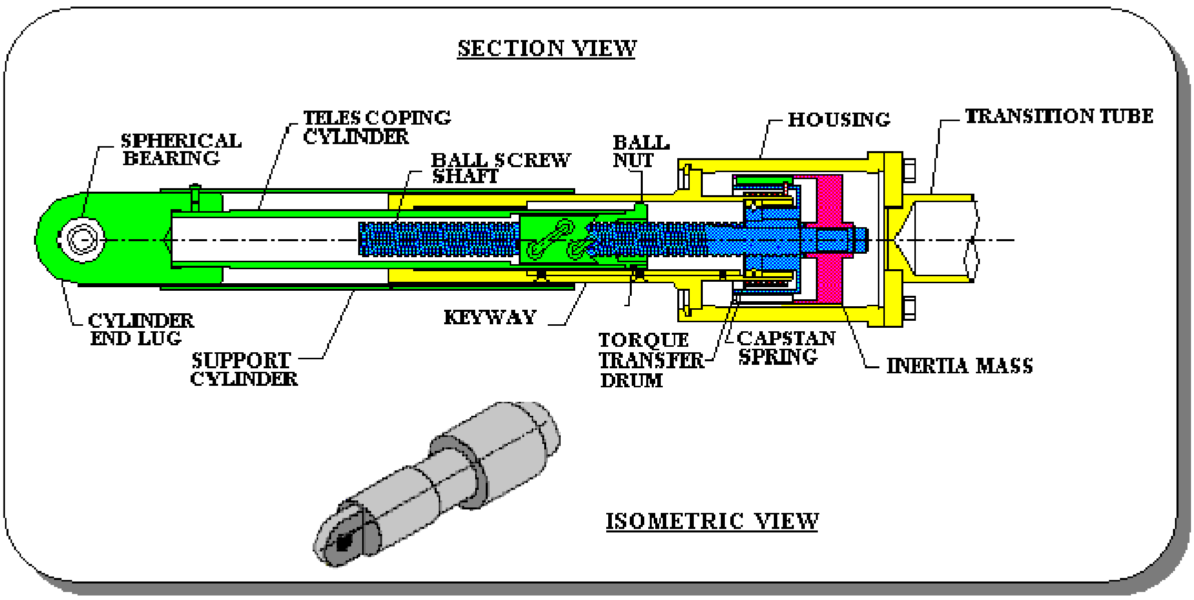

Figure 18. Mechanical snubber assembly (Wikipedia, 2011)

Figure 19. Mechanical snubber on site (Wikipedia, 2011)

Process impulse events, covered by mechanical snubber action:

- water hammer
- tripped valve
- pipe rupture
- protection from overtravel

External impulse events:

- seismic event (such as an earthquake)
- unexpected failure of adjacent components
- high wind loads
- explosion

It should be noted that due to various stress conditions in process piping systems, all three types of pipe supports can be combined and used for the certain piping system in order to meet requirements for thermal and pressure induced expansion and shrinking of the piping system.

3.4.2. Pipe support function in piping system integrity

A pipe support point is an interface point between pipe and pipe support structure where high acting loads can, theoretically, cause intensive deterioration of both pipe wall and pipe support frame. However detrimental effect of water presence at pipe support points is by far stronger than exposure to intensive loading. According to Britton (2002), statistically, corrosion at pipe supports is the most common cause of external piping corrosion failure. Let's look deeper at pipe support related corrosion.

3.4.2.1. Problems caused by undesirable pipe support features.

Below there is a list of pipe support inherent features which aids unfavorable developments to arise, presented by Britton (2002):

- **Forming of crevice**. The formation of crevice at the pipe surface is the root of corrosion problem

- **Water trapping**. Conventional and natural pipe support design, both framework design and standard detail design, is responsible for water trapping.

- **Poor inspectability and maintainability**. Due to odd piping and pipe support design and layout, components of the piping system are often installed so dense that it is virtually impossible to paint or maintain some areas of the pipe at the support. Visual inspection and NDT methods are also very difficult to perform.

- **Galvanic couple forming**. Some types of pipe supports may develop bi-metallic contact between pipe and pipe support, so that, despite that both the pipe and pipe support are of the same, say CS steel, the metallurgical differences can give rise to a small potential difference that can drive a corrosion cell.

3.4.2.2. The typical pipe support corrosion mechanism.

Britton (2002) provides fairly accurate description of pipe support corrosion mechanism sequence:

1. **Water is trapped.** The pipe supports nature makes it possible for water to be held in contact with the painted surface.
2. **The paint system fails**. Even though the painting of the pipe and pipe support beam are perfect, it comes up a problem because the paint system is designed for atmospheric exposure rather than for immersion and soaking. Continuous exposure to water makes the paint surface soften. Softening of the pipe leads to direct exposure of the steel substrate to the water
3. **Corrosion initiation**. The small area of steel gets exposed to oxygenated water (containing typical for environment chlorine) and corrosion starts
4. **Corrosion undermines paint film**. Corrosion develops fast and undermines the paint surface. As a result the area of pipe, which is in contact with the support steel, gets naked (see figure 20).

Figure 20. *Progressive paint destruction (Britton, 2002)*

5. **Start of crevice corrosion**. From this point on the crevice corrosion driven by differential aeration takes over from the general corrosion mechanism that initiated the corrosion. As corrosion products build they further restrict oxygen diffusion and the oxygen concentration gradient gets steeper. Pitting now becomes the main problem with corrosion rates acceleration by an order of magnitude (see figure 21).

Figure 21. *Advanced crevice corrosion (Britton, 2002)*

6. **Failure of pipe**. If this concealed wall loss is not detected by inspection program the pipe will fail soon.

3.4.2.3. Pipe support solutions for corrosion free performance.

In spite of operator's awareness of the corrosion problem at the zones of pipe and pipe support contact, many of them have wrong appreciation of true causes of the problem. Some of the solutions used to stop this corrosion problem, actually accelerates it.

Since, previously, it was believed that the metal-to-metal contact is the main problem that causes pipe support corrosion, pipe support designers often targeted this aspect of the problem. It is strange, but some operators still approve the use of rubber pads to solve the corrosion problem (I guess traditionally) when it is widely known that application of rubber pads is actually counterproductive. Rubber pads installed under pipes significantly reduce the life of the pipe, since the crevice which is formed without the rubber pads is rather harmless compared to the crevice caused by rubber pad, which sucks water in and hold it trapped around the pipe surface. There is a perfect illustration of this wrong approach on the figure 22, below.

Figure 22. Rubber pads accelerate crevice corrosion (Britton, 2002)

Nevertheless many operators appreciate and realize the true root causes of the corrosion problem and follow relatively simple principles for developing the solution which enables effective addressing the problem. These principles are presented below:

1. Elimination of crevices at the pipe surface and ability of trapping and holding water
2. Elimination of metal-to-metal contact
3. Design should be sensible to allow easy maintenance and inspections of the support point.

The concept, which meets the abovementioned requirements, is the half round, high strength thermo-plastic I-rod, illustrated on the picture 23 below:

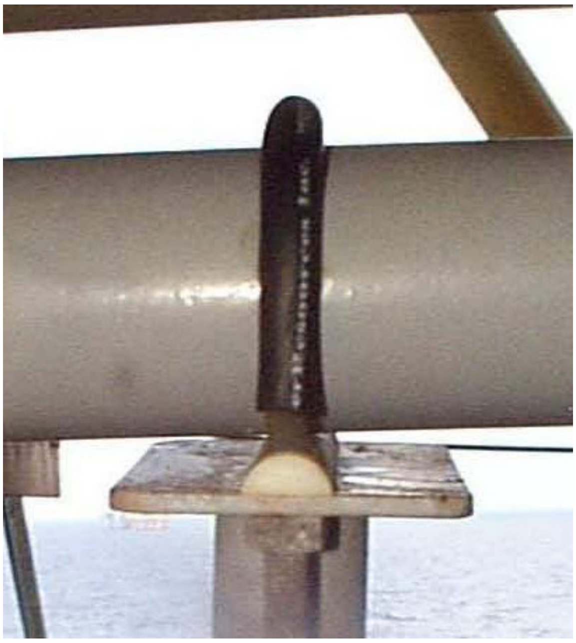

Figure 23. Thermo-plastic I-Rod (Britton, 2002)

The half round configuration of the I-rod, reduces crevice at the pipe surface and makes it impossible for water to trap. Moreover, thanks to gap created by I-Rods between the pipe and support frame, the pipe can be easily inspected and maintained.

3.5. Case study. Organizational and operational issues causing corrosion damage.

On one of the aging offshore platform on the NCS, where the thesis's author had pleasure to carry out many offshore surveys corrosion problems are more than noticeable. Process area of this platform contains such equipment as first stage, second stage and test separators, several compressors including export compressor. All this units of critical equipment are interconnected by piping of various size and specification. Majority of pipes are insulated. Insulation is also installed on separators. Piping is supported by numerous pipe supports including both standard (rigid) pipe support solutions and mechanical snubbers (dynamic pipe supports).

The most remarkable thing at this process area is a roof. The roof is constantly leaking. Leaking leads to humid atmosphere, damp on structure and equipment not to mention intensive dripping causing direct access of water to all process objects inside the module area.

At the same time there are quite many defects of insulation. Majority of defects are represented by improper installation cases of the past years and surface damages of jacketing. There are some cases where insulation was partly removed for some reason so that interior part of remained insulation was exposed to adverse environmental impact and soaking, ultimately insulation was installed and it remains to be seen whether inner space under jacketing was sufficiently soaked to cause corrosion process on pipe surface.

There are also many corroded CS pipe supports in the area, with the signs of deep corrosion that should have got more maintenance. Significant corrosion damage is not only the result of water influence but also result of combination CS and SS without sufficient galvanic isolation between two materials, thus CS structure elements are significantly deteriorated by corrosion since they became sacrifice anodes for SS elements.

Special attention of the author was attracted by snubber supports installed in the process area. Since the function of the snubber supports were to impede possible, adverse explosion impact, the pipes supported by the snubber supports were not even qualified for blast forces or in other words, in case of explosion the snubber supports are responsible for taking excessive forces by means of restraining pipe from rapid movement. However due to high air humidity and contact with water the snubbers rusted out both outside and inside (see figure 24), so that mechanisms inside got stuck, and rather than to be a dampers and absorb energy of explosion the snubber supports became the restraints with anchor functions creating redundant strain, this may result in pipe wall rupture or disconnection of flange joints. Situation became aggravated when risks of falling pieces of corroded snubbers were estimated fairly high. Ultimately snubber support replacement project was initiated.

For comparison snubber solution applied in dry areas (see figure 25) of the platform have been demonstrating perfect performance since early 90-th when platform was put in operation, but nevertheless snubber solution was counted by some “advanced” authorities a wrong one and decision were made to demolish all of them despite technical state. Isn’t it a sign of being unwilling to search for the root of corrosion problems? In the author’s opinion it is, but more than likely it is additionally conditioned by wrong management perception of technical questions, also wrong focus and priority.

Figure 24. Corroded snubbers and pipe after insulation removal in the process area with high humidity due to, among other things, leaking roof

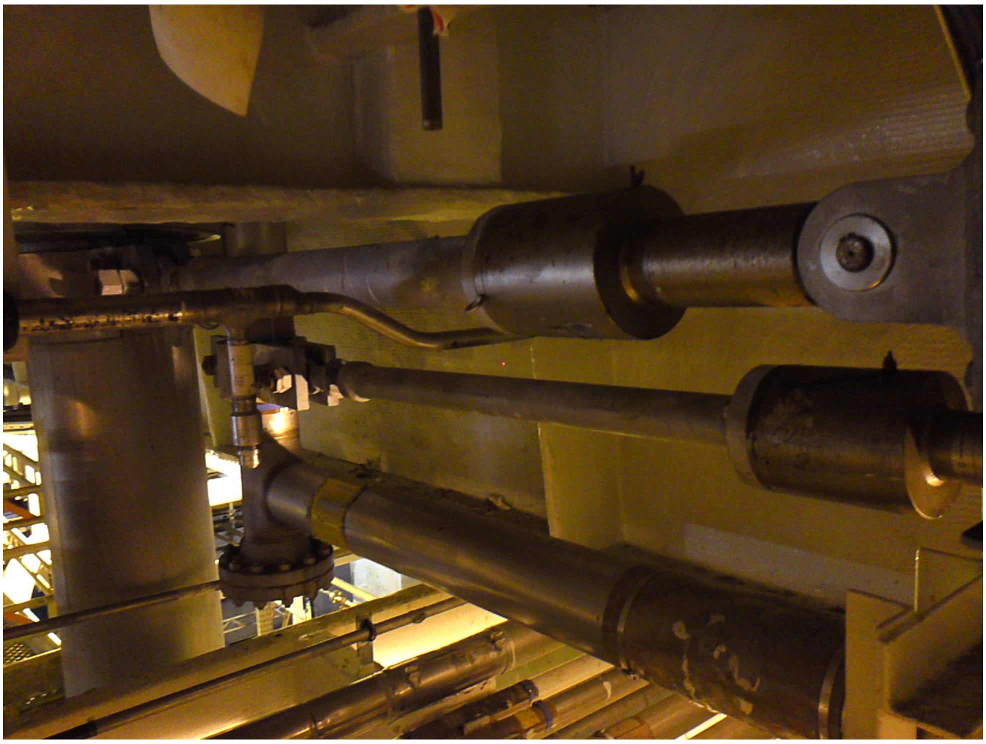

Figure 25. Snubbers in perfect state in dry process area.

In support of the author's point about wrong management attitude, he would like to give an ironic example. The last year was the rush on that platform, there were many minor modification sub-projects within M&M project. One of these projects dealt with leaking roof…above living quarters, to be exact minor signs of leakage. The task was to replace 48m^2 of roof. Many disciplines were involved, including piping (due to need for temporary pipe supports), structural, architectural, installation and methods, commissioning, safety and others. Besides it was installed a so-called habitat, or welding isolation chamber allowing to weld offshore safely and prevent from possible ignition. Moreover it was installed weather tent. Huge job was performed to eliminate minor signs of leakage. However the roof of the process module was still leaking and none was worried about it, unfortunately.

4. Material selection in marine environment.

Choice of materials for offshore process piping is fairly broad. Below there is a list of material alternatives that can be used offshore for piping equipment with different properties and resistivity to corrosion presented by Heselmans (2006):

1. **Stainless steel** (SS) is ranging from 316L, duplex SS to 6% Mo SS. 316L series is considered not to be resistive to seawater, so the minimum choice against seawater is duplex 2205. For that alloy, chlorination of the water is a requirement, and the temperature should not exceed 20 °C (e.g. North Sea). In tropical water with temperatures up to 40 °C (e.g. in Persian Gulf) the minimum requirement for chlorinated water is super duplex SS. Crevice corrosion is a major concern, even for super duplex SS and 6% Mo SS.

2. **Use of stainless steel and controlled cathodic protection.** Under certain circumstances, controlled cathodic protection, works very well for avoiding localised corrosion and galvanic corrosion. By use of cathodic protection, the materials selection can be downgraded, thus there is a saving.

3. Use of **copper alloys**, such as Cunifer and Cupronickel. The alloys should only be used at low flow rates or stagnant water. Erosion corrosion occurs at higher flow rates or in areas of turbulence, e.g. in heat exchangers.

4. Use of **GRE**'s (Glassfiber Reinforced Epoxy). There is none corrosion in GRE pipes, but nevertheless they are not suitable for complicated geometries or constructions such as tubular heat exchangers. Besides GRE piping is sensitive to mechanical shock or vibrations.

5. Use of **Titanium**. Titanium pipes do not develop corrosion, but hydriding is possible if a cathodic protection system or galvanic corrosion polarises the titanium too much. Disadvantages of titanium are high prices and long delivery time.

6. **Carbon steel (CS), uncoated**. Without cathodic protection CS can develop corrosion rate up to 1 mm/year. For internal piping, cathodic protection of carbon steel is no option because anodes distance would be too close for economic performance. For stainless steel internal cathodic protection is an option because of the current demand compared to carbon steel is much lower.

7. **Carbon steel, coated.** Suitable for the internal of vessels, but not for the internal of piping, heat exchangers and smaller parts.

The list of materials impresses and prompts to think that thanks to such a wide choice, a suitable solution can be found for absolutely all projects' needs. Operators may select less expensive CS solutions for the short-run project where OPEX impact will not play important role, for some purposes GRE piping can be used to limit the impact of OPEX etc.

It should be noted that each material has pros and cons, both technical and economic, and right choice of material or combination of materials for piping system is a significant step towards corrosion-free performance and, hence, integrity of the piping system.

At the moment there is a pronounced tendency to utilize more and more SS piping offshore of various grades and M&M projects are busy with replacement of old carbon steel piping with stainless steel alternative aiming to get rid of or at least reduce adverse effect of corrosion. According to popular belief SS is a remedy for corrosion and some management persons are convinced that SS choice is perfect means of corrosion prevention, this makes them excessively self-assured with regards to proactive approach to countermeasures against corrosion. However, Heselmans (2006) asserts that a 25Cr07Ni super duplex tubular heat exchanger in a marine vessel shows crevice corrosion within six month of service. Then, the author guesses, maintenance and management personnel should be sensitive and hands-on in terms of corrosion problems even though SS piping is installed and operates.

5. Corrosion phenomena with SS in marine environment.

5.1. Localised corrosion

As a rule, in marine environment SS will never corrode uniformly. Corrosion is localised, in other words there are pitting corrosion and crevice corrosion. Localised corrosion is frequently being promoted by a biofilm. Figure 26 depicts an example of crevice corrosion in a seawater cooler.

Crevice corrosion is a major concern for SS piping in marine environment because of the low resistivity of the water (seawater resistivity is about 0,35 Ohm.m). Even 6% Mo SS at 30℃ can suffer crevice corrosion in seawater. However, chlorinated seawater below 25 ℃ will not cause pitting corrosion to duplex stainless steel 2205 (Heselmans, 2006).

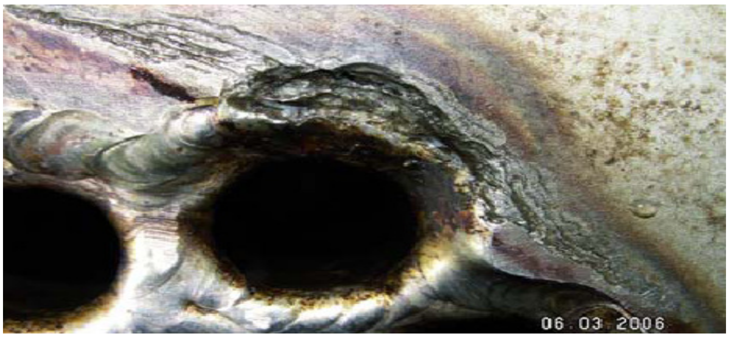

*Figure 26. Crevice corrosion in seawater cooler finally leading to leakages. (*Heselmans ,2006)

5.2. Galvanic corrosion

Like crevice corrosion, the low resistivity of seawater also promotes strongly galvanic corrosion. Galvanic corrosion is seen as a major concern for materials performance in marine environment. A well-known example is bronze bearings in ships, where sacrificial zinc anodes need to protect the steel hull for galvanic corrosion. Also SS can suffer galvanic corrosion, or it causes galvanic corrosion to other, less noble, alloys (Heselmans, 2006).

5.3. Stress corrosion cracking

At temperatures above 60 ℃ SS 304 and 316 are sensitive to chloride cracking. Duplex stainless steel and 6% Mo are much less sensitive to this phenomena, however under extreme conditions, i.e. high temperature, high stresses and cold deformation it may occur. Sometimes stress corrosion cracking occurs from the outside, especially longitudinal welded pipes at higher temperature are sensitive to this type of corrosion under insulation.

6. GRE piping systems.

Current pronounced tendency of operator companies to reduce lifecycle costs of pipework prompt them to use alternative, non-metallic corrosion resistant materials, and GRE (glassfiber reinforced epoxy) piping looks especially attractive. High industrial interest to GRE technology and its growing application makes the technology attractive for deeper research with purpose of verifying its real performance potential.

6.1. Introduction of GRE technology.

GRE pipeline systems are made from glass fibers, impregnated with an aromatic- or cyclo-aliphatic amine cured epoxy resin. GRE pipes are manufactured using the filament. In this mechanical process, continuous glass fiber rovings are impregnated with epoxy resin. The production of GRE starts with the preparation of a steel mandrel, which may be completed with a socket mould.

The dimensions of these tools determine the inner dimensions of the pipe, fitting and joint system. Glass fibers are guided through a resin bath, which is filled with epoxy resin and are wound under constant tension in a specific pattern around the polished mandrel (figure 27). This process continues until the required wall thickness is reached. Generally, the higher the pressure class, the greater the wall thickness of the product will be. The winding process ends with curing the epoxy resin in an oven, extraction of the mandrel/mould from the product, finishing the product by cutting to length and machining the ends (Future Pipe Ind. 2010).

Figure 27. Manufacturing of GRE pipes.

As it was discussed earlier all metallic pipework, independent of material, is subject to some of corrosion mechanisms to a certain degree. It implies that considerable part of OPEX will be presented by preventive measures against corrosion attack or elimination of corrosion related defects. Performance based philosophy of operator companies management motivates them to check and find various ways of OPEX reduction and many operators choose to replace conventional metallic piping with non-metallic alternative.

Interest to piping polymeric materials tends to grow substantially, production pace picks up steam and bright future for the branch seems to be guaranteed. But like there is no rose without a thorn, there are no absolutely perfect technologies and the author's task is to verify GRE technology and try to find possible drawbacks. It is necessary to clarify the question of GRE pipes durability, reliability, application limitations and typical bottlenecks.

One of the leading GRE producers, Future Pipe Industries Group, supplying some of Norwegian O&G operating companies on the NCS, lists a number of advantages and disadvantages inherent to GRE pipe systems against conventional pipe systems.

6.2. Advantages of GRE technology presented by the manufacturer

1) GRE pipes are durable and corrosion resistant both internally and externally, to the corrosive effects of water, oil and many chemicals, without need for cathodic protection.

2) GRE pipes have low weight and easy to install. The specific weight of GRE is only 25 % of steel. Due to the low weight, GRE piping components are easier to handle without the need for heavy (lifting) equipment.

3) There is no initial painting or conservation required. The epoxy topcoat on the outer surface of GRE pipe components is resistant to the influences of the installation environment and an additional external conservation is initially not required.

6.3. Disadvantages of GRE technology presented by the manufacturer

1) Low impact resistance. The pipe system is more susceptible to impact damage due to the brittle nature of the thermoset resin system.

2) Handling. GRE installations require more and careful preparation due to other joining methods, handling- and transportation requirements and installation techniques compared to conventional metallic piping.

3) Excessive flexibility. The flexible GRE piping system requires specific support design.

At a first thought tired of corrosion problems managers might see a sovereign remedy against it in GRE technology. Sure enough, there is total disposal of corrosion problems, no need for surface protection along with significant savings on delivery and installation of low weight pipes. But if these managers take a look at GRE pipes disadvantages some disappointment might come up and it is not for nothing.

The authors decides to take a look at disadvantages of GRE mentioned by the producer and look deeper at the disadvantages omitted by the manufacturer by evident reasons.

6.4. Analysis of GRE technology disadvantages mentioned by the manufacturer.

6.4.1. Low impact resistivity of GRE piping.

Susceptible to impact damage conditioned by the brittle nature indicates that **area of application is limited** to relatively remote location of platform where there is a low risk of surface damage due to various activities like operation and maintenance of process and other equipment, repair and modifications. Otherwise GRE pipework must be surface protected from damage that in turn contributes to CAPEX.

6.4.2. Handling of GRE piping.

GRE pipework is a challenge for operators in many terms. Piping must be prepared and installed in certain manner, special attention is to be paid to uncommon joint connections which may cause leakage unless treated properly. Special procedures are developed by the manufacturer for installation and it is preferably to have the manufacturer's representative for supervision under installation because the procedures provided by the GRE manufacturer may be not sufficiently clear for the pipe-laying contractor, thus contractor should be certified by manufacturer. Installation team should be extremely careful with pipes during installation since in case of damage, the delivery of a new spool replacing the damaged one can take some weeks, this means that installation process must be suspended and important milestones subject to delay.

6.4.3. Flexibility of GRE piping.

Due to more than normal flexibility GRE piping system requires specific design along with pipe support design. GRE lines have shorter than metal pipes span, thus a designer should take care of more pipe support points and available structure for pipe support connecting. Consideration is to be taken to position of valve and other relatively heavy elements which should be supported independently of pipe itself.

6.5. Analysis of GRE technology disadvantages not mentioned by the manufacturer.

6.5.1. GRE piping sensitivity to mechanical vibrations

Due to sensitivity to mechanical vibrations GRE materials cannot be used for process piping connecting to mechanical equipment like pumps and compressors. This drawback limits GRE pipes application additionally, along with impact resistance factor. And operators should keep this in mind and strongly avoid GRE pipes application outside the permitted area for safety reasons. GRE technology is more suitable for ships other than for offshore process plants because of criticality of the process, or it is very suitable for less critical systems of process facilities like drain and water services.

6.5.2. Microstructural quality issues of GRE piping.

Frost et al (2005) describes two case studies where the leakage during hydrostatical testing of GRE piping occurred. Further microstructural investigation indicated three possible manufacture causes of these leak paths as follows:

- Poor impregnation around deficiencies in the filaments
- Poor temperature control during resin curing resulting in voids
- Poor wetting of the fibres, leading to a leak path from the pipe interior.

Thus quality of GRE piping is another possible problem for operators and it should be taken in account before planning of modification project since delivery time of new spool and aforesaid information prompts to think carefully about quality control of GRE pipes.

6.5.3. Long-term behavior of GRE pipe systems.

Majid et al (2005) at their research of the long-term behavior of GRE pipes underline the importance of predicting behavior of GRE pipes in 20 – 30 years perspective under complex loading based on the data recorded from short term failure tests. This information is definitely extremely important for operators since durability of GRE pipes is crucial for both safety and economical reasonability of GRE pipes alternative.

The failure behaviour of GRE pipes has been the subject of investigations for many years now, the majority of which were emphasized on the long term design limits, failure mode and associated deformations. This is complicated by the fact that GRE pipes are not just anisotropic materials but also inhomogeneous. As a result, a variety of mechanisms of failure can be observed from GRE pipes subjected to uniaxial or biaxial loading such as matrix micro-cracking, fibres fracture, delamination or fibre-matrix deboning, which limits the use of GRE composite pipes (Majid et al, 2005).

Aforesaid information seems to be the biggest drawback of GRE technology since without proper knowledge about defects in future consumers do not have evident reasons to decline conventional metallic piping in favour of GRE piping system.

6.6. Conclusions about GRE technology utilization.

Despite perfect corrosion resistance and other benefits GRE pipework is quite deniable alternative to steel pipes. Utilization of GRE pipework is only justified when OPEX is guaranteed to be really low, since CAPEX are significantly higher than for metallic pipes. And it is a big question if company taking in consideration listed disadvantages. The author of the thesis would suggest that GRE technology is perfect for short-run projects like those on Statfjord A platform on the NCS. Since the platform is expected to be decommissioned in about 5 years the operator widely utilizes GRE piping for lower critical water service systems. In this case it looks fairly justified, since risks are really negligible at such GRE pipework employment. It is absolutely another thing when an operator makes a decision to use GRE piping for hydrocarbon system, long-term or around operational limits.

Frost et al (2001) emphasizes that their experience with this GRE pipeline demonstrated that the manufacture of relatively large diameter GRE pipes for high pressure applications requires improved fabrication procedures, additional test requirements to verify the material quality, and adequate procedures for transport, handling and assembly.

If company has made a decision to utilize GRE then it needs to treat to these arrangements as seriously as possibly. Above all proper relationships with manufacturer should be established for consulting, better planning and continuous follow-up of the GRE piping system. Moreover it is required strict quality assurance and control during installation because even though GRE piping is of high quality, poor installation can easily trigger serious integrity issues which will show up in some time. Elimination of defects, in turn, entails range of complex and costly activities including system shut down, waiting for new spool delivery and subsequent testing of piping. Consequently LCC might become unacceptably high exceeding LCC of metallic solutions, and then GRE system utilization is no longer practical and viable, seemingly perfect alternative loses its relish completely.

7. Piping vibration.

Sufficiently big portion of M&M activities is presented by replacement of old corroded CS piping with new SS pipes produced from various grades of SS, from 300 series SS to super duplex 6Mo. Besides non-metallic alternatives like GRE pipes get more and more popular. Modification projects very often presents cases of partly removal of piping branches, leading to pipe to pipe interface represented by combination of dissimilar materials, so that new SS or GRE piping spools become connected with old CS piping.

It often takes place that switch of piping spools is not regarded as something serious and responsible. As a result of such an underestimation pipe stress reassessment is often too surface or even left out at all so pipe support position and functions become unchanged. Meanwhile modification can easily violate design parameters and stress balance of piping system.

Disregard for pipe support position is unacceptable because two connected piping spools made of different materials have different physical properties and wall thickness. Pipe support functions may require reassessment to balance piping system under new stress conditions. Thinner wall thickness of new SS pipes may require shorter pipe support span, otherwise deflection can emerge so that pipe system behavior differs, and this gives rise to increase of frequencies or coming up of vibration. In severe cases the pipe can fracture due to fatigue, in less severe cases vibration leads to bolt unscrewing at flange connection and subsequent leakage, at the same time under influence of vibration unfastening of pipe support details often happens, what is the cause of even higher vibrations and onset of severe consequences.

From other hand a pipe will not vibrate if it is prevented from moving. However, this does not necessarily help the piping system design from the standpoint of its ability to absorb differential thermal expansion. Therefore, when addressing a vibration problem, the flexibility design of the piping system must also be considered. Restraints that are added to reduce vibration must not increase the pipe thermal expansion stresses or end-point reaction loads to unacceptable levels. It may sometimes be necessary to use hydraulic snubbers to stop vibration rather than fixed restraints. Such snubbers permit pipe thermal movement while still dampening vibration (Carucci, 2010).

Consequently while modifying piping system stress analysis should be performed in extremely proper and diligent manner so that stress balance of the piping system was retrieved and even improved, considering a fact that old design was far from perfect and it does not comply with current standards based on enhanced risk and maintenance awareness. Moreover old piping weakened and deteriorated by detrimental effect of various types of corrosion over long time of poor maintenance becomes quite vulnerable and susceptible to vibration. Disregard of risks conditioned by combination of corrosion and vibration can easily lead to unpredictable consequences and this fact should be taken into account by senior management.

8. Piping system integrity barriers (PSIB) on ageing platforms on the NCS.

Since this thesis work's major objective is to identify barriers of process piping integrity on offshore platforms, it is necessary to provide more or less clear definitions of the terms "asset integrity" and "barrier" in the context of global oil and gas practices. There are many various versions of definitions of these terms and the most suitable, in my mind, are presented below.

According to guide of International Association of Oil & Gas producers (OGP, 2008) "asset integrity is related to the prevention of major incidents. It is an outcome of good design, construction and operating practices. It is achieved when facilities are structurally and mechanically sound and perform the processes and produce the products for which they were design."

This guide provides also definition of barrier as follows: "Barrier is a functional grouping of safeguards and controls selected to prevent the realization of hazard. Each barrier typically includes a mix of: plant (equipment), process (documented and 'custom and practice') and people (personal skills and their application). The selected combination of these elements ensures the barrier is suitable, sufficient and available to deliver its expected risk reduction."

In the author's interpretation and in relation to this thesis work, the term "piping system integrity barrier (PSIB)" can be defined as a measure or a set of measures aimed at preventing the development of the worst-case scenario as a result of failure or defect in a piping system by means of good design, construction, operation and maintenance. In the context of the integrity problems illustrated earlier in the thesis, the author would like to focus on barriers against corrosion and vibration problems in piping as serious failures. Corrosion of piping can easily trigger leakage (see figure 28) of crude oil, gas or hot water, and it is clear that consequences can be extreme and unpredictable. At the same time corrosion problem in process piping system is fairly controllable process and can be successfully governed throughout piping system lifecycle by means of barriers in economic way.

Senior managers should involve piping integrity barriers in work procedures so that thereafter to translate them into work flow. Thus risk awareness and barriers perception can be attached to all project activities critical for corrosion and vibration prevention. These activities include piping and pipe support related design, choice of material, surface protection and installation, pipe stress calculation and in addition insulation's spec choice, design and installation. Piping integrity barriers should also be included in maintenance procedures of upgraded pipe system to ensure optimal lifetime, performance and reduced OPEX of the system. In other words, creation, implementation and maintaining of piping integrity barriers is a matter of management determination.

Figure 28. Leakage in a CS pipe

Barriers for prevention of corrosion and vibration hazard in piping systems throughout lifecycle.

Severe corrosion and vibration problems of process piping on ageing platforms can only be avoided if piping integrity is seriously considered throughout lifecycle of a pipe system and integrity barriers are developed and maintained on each stage of the lifecycle. The stages of a piping system lifecycle where piping system integrity barriers (PSIBs) are possible to apply can be classified as follows:

- Concept selection
- Asset definition
- Detailed design
- Construction and commissioning
- Maintenance, modification and operation (MMO)

8.1. PSIB at the concept selection stage.

Piping integrity costs and effectiveness throughout its life can be positively influenced by means of optimizing early choices of design. Since optimization is time and resource consuming undertaking, it is a strong requirement for leadership that can recognize and balance piping integrity along with overall lifecycle costs against sensible design with lowest capital costs or shortest period of construction.

It is obviously that some designs concepts are inherently have higher reliability level than others. It is necessary to identify key hazards and the barriers required for control of these hazards, because it will help to get rid of concepts where piping integrity issues are hard-to-manage. Concept design choice may contribute to determination of other operation and maintenance activities which will exert own influence on piping integrity risks. This stage of piping system lifecycle is decisive in terms of maintainability of the system, focus on maintainability of the equipment will benefit in future by reduction in maintenance time and hence costs, besides safety benefits much thanks to simplified equipment-operator interface.

The author of the thesis would like to give an example of concept selection where corrosion resistance capability is emphasized. The author considers two design alternatives for high pressure piping system with highly corrosive process fluid, like crude oil with high H_2S content etc. The first option can be a corrosion resistant, duplex SS pipework that is fully rated for maximum pressure. The second option can be less corrosion resistant, CS pipework rated for normal process pressure but with provided instrumented pressure protection and injection of corrosion inhibitors to maintain piping integrity. It goes without saying that the first concept has less potential to fail as a result of corrosion attack or overpressure compared to the second option, however the costs of the first choice might be higher and also any uncertainties might exist like susceptibility of duplex or 6Mo material to erosion, requiring additional inspections. Hence it is a question of a discussion which of these two concepts is the best in a certain operational context.

Thus piping integrity barrier through sensible concept selection is very important thing. It is very important to clearly set performance standards for piping integrity barriers at this stage in order to have fair comparison of all options, because real future costs of maintenance and operation can be easily underestimated. Thus it can be insufficient investment in piping integrity capital equipment. It is important to bear in mind that as soon as design concept is selected, available flexibility for eliminating hazards, decreasing risks and simplifying piping integrity management, drops significantly. Special attention is to be paid when selecting material for future piping system. As it was discussed earlier in the chapter about material selection in marine environment, the choice of material is fairly broad but there is a need for special expertise for making right choice. Final solution about piping material should consider both barriers for the piping system integrity in the current operational context and overall costs of the selected alternative, both CAPEX and OPEX.

8.2. PSIBs at the asset definition stage.

After development of piping system design, the barriers to maintain piping system integrity must be worked in parallel. It must be defined overall performance standards for the main barriers, thus performance standards for systems and sub-systems should be ready for determining. In such a way, equipment specification will take in consideration maintenance needs and operational capacities.

For example it is not so reasonable to plan 96% uptime of piping system if it requires two weeks inspection downtime annually, because in this case there will not be provided contingency for possible planned or unplanned downtime.

During this stage of life cycle it is required to ensure maintenance, inspection and testing requirements for barriers, along with estimates of piping system downtimes.

It is helpful to compile a catalogue of applicable codes and standards, since this catalogue will simplify a dialogue between participants of design team, so that the potential for misunderstanding and arguing about required barriers and performance standard can be reduced. Besides, if appropriate codes and standards are identified and applied, it is possible to estimate residual risks by means of comparison with similar piping systems already installed on the given platform or with other offshore platforms utilizing such corrosion resistant piping systems.

8.3. PSIBs at the detailed design stage.

By this stage, most important piping system integrity decisions have been made. But, piping system integrity can be considerably spoiled by improper detailed design, so that planned barriers can become ineffective. In order to catch up with the best practices in detailed design, it is necessarily to have full documentation describing the future piping system design, including operating and maintenance strategies and methodology of major hazards management. All the barriers must have developed routines for maintenance and inspection. Estimation of risks must illustrate that hazards and risks are dealt with in appropriate way by means of piping equipment specifications, procedures and responsibilities assigned, and, of course, competent personnel. During this stage maintenance and operation teams should start familiarization and operability reviews, which must be kept on until the construction stage starts. By the end of detailed design stage all PSIBs must be thoroughly identified and documented.

At the detailed design stage operational and maintenance requirements of the future piping system should be considered in a way that all operating and control points, including valves, flanges, instruments, drains, sample points and vents, would be located where safely and easy operating is possible. A designer should take care of sufficient space in operating and control points.

If the CS option mentioned earlier was selected for the piping system, then considering material's susceptibility to corrosive fluids, allowance for extra maintenance activities must be made through including in the design corrosion monitoring fittings or drop-out spools.

Besides the layout of pipework should not have branches with length exceeding three pipe diameters which can be at stagnant state. That is because corrosive fluid and possible deposits can collect at the bottom of this section and accelerate corrosion pace.

Sensible solutions for pipe supports should be used, like thermo-plastic I-Rod for U-bolts and U-straps described in the pipe support chapter earlier. Despite its simplicity, I-Rod concept both favorable for pipe surface protection and access during inspection round.

During the detailed design stage operator has chance to influence future OPEX and safety of the piping to a great extent. In fact, if relevant concept of the piping system was selected, proper detailed design, through fairly straightforward solutions, can even more enhance system durability and maintainability. Thus decent detailed design can be another strong barrier for the piping system integrity if maintenance quality on the platform is not high enough, as it was described in the case study chapter earlier.

8.4. PSIBs at the construction and commissioning stage.

As regards piping system integrity, this stage is quite critical, since there is risk of improper installation of pipe supports or piping insulation by low competent personnel. As it was discussed earlier employment of low competent work force, with language skill deficiency is a big problem for this very stage. Improper installed pipe supports can cause vibration, where poor quality of insulation installation is precondition to CUI, discussed in detail in the corrosion chapter earlier.

During this stage of piping system life cycle possible design changes might be necessary. In this case, it is very important that these design changes would be appropriately managed and authorized in order to guarantee piping system integrity standards retention.

It is vital to complete all required procedures for operating, maintenance and testing prior to commissioning starts and required personnel is assigned and trained. In such a case it is more or less guaranteed that the procedures and human elements of major incidents barriers function at the initial step of piping system operating.

8.5. PSIBs at the maintenance, modification and operation (MMO) stage.

This stage of piping system life cycle is of great interest when we discuss M&M projects. Maintenance part of M&M project on offshore platform is to implement and maintain piping system integrity barriers identified in the earlier stages of its life cycle. So, regarding to corrosion problems, M&M project should effectively counter the detrimental effects on piping surface by means of well-organized processes of corrosion control, effective methods and clear distribution of roles and responsibilities. In terms of modification, M&M project should ensure that changes of ageing and critical, existing piping system design, operating limits or maintenance frequencies will be made in reasonable way, so that change control and review would be performed by appropriate and competent technical authorities.

For example, if the part of CS piping system is to be partly replaced by duplex pipes, the system should be carefully re-estimated by stress group in order to provide possible changes in pipe support amount or functions to avoid deflection and vibration problems that can create excessive stress case for adjacent, mature CS piping or nozzles of connected static and dynamic equipment within the system, like separators, scrubbers, pumps and compressors.

It is obvious that smart choice of piping design solution on the earlier concept selection stage leads to reduction or elimination of hazards, so the need for intervention, maintenance and testing task is significantly reduced. However, at this stage of piping system life cycle, it is important to check the performance of barriers on regular base to reveal and deal with possible deficiencies, both inherent and caused by modifications, appropriately. Such a testing is particularly important for piping system with higher hazardous process fluids, like hydrocarbons containing H_2S, or extreme operation conditions, like high pressure and high temperature reservoir conditions, e.g. Kristin TLP platform in the Norwegian Sea.

Understanding and communicating major incident hazards is vital for operational and maintenance management. The managers must have competence to present how the design of the equipment and procedures can provide surefire and proper barriers for piping system integrity, that comprise also recovery from performance deviations.

It is clear that, as long as operating conditions change gradually during production life of an oil field, an initial design concept may become unreasonable at the current operational context. All these serious changes can impact on operating limits and the change control process should consider these changes. It is worth noticing that codes and standards always changes over time, so the original design of many piping system developed in 70-th and 80-this no longer valid at all. It is actual fact for some platforms on the NCS visited by the author for surveys. So the role of M&M project here is to review original piping design against such regulatory changes and to assess the extent of modifications required in order to reduce newly estimated risks. Consequently modification will probably be required even though a piping system is in good technical state without signs of corrosion or other defects.

8.6 Balancing piping integrity barriers performance against profits

It worth keeping in mind that any M&M project on ageing offshore production facilities is a business. Every service engineering company providing M&M services is interested in profit maximization and continuous business development. Many M&M service provider tries to reduce costs in any possible way and it often happens that they sacrifice piping integrity barriers for cost cutting unconsciously. Global tendency to cut costs through partly relocating businesses to the regions with favourable business conditions was fully appreciated by Norwegians M&M service companies.

8.6.1. Challenges related to utilization of remote offices in Asia.

Tough competition in Norwegian O&G sector encourages suppliers to find different ways of cost reduction. One of the most attractive ways to save for some service companies is use of cheaper work force from abroad. Project engineering performed in south-eastern Asia is several times cheaper than equivalent job performed in Norway. Owing to such a big difference in labour costs senior management is eager to seize this golden opportunity. Some Norwegian service providers have offices in Mumbai, Singapore etc., where local engineers are employed and work remotely on the M&M projects for Norwegian platforms driven in Norway. Asian engineers have good reputation worldwide that in conjunction with good education and expertise makes them right and desired candidates for M&M project work.

Idea of saving through cheaper workforce is fairly sensible, but in reality the implementation of such complex intercontinental projects is a big challenge. A head office in Norway and a region office say in Mumbai are, in fact, two fairly unlike organizations despite belonging two one company, and effective collaboration is barely possible unless proper efforts to align activities of two units are made. Sharing job with an Asian office has some particularities those do not tolerate any neglect otherwise potentially promising undertaking might become a real headache causing issues for project implementation and reducing performance, so that piping integrity can be at stake.

8.6.1.1. Time difference.

Due to 3,5 hours' time difference between Norway and, for example, Mumbai there is only 4 hours a day for joint activity on a project. Squeezed timeframes can have negative effect on task execution when involvement of both sides is required. It might occur that possible organizational, technical, managerial etc. issues of various degree of importance coming up in both head and remote offices must be suspended and postponed until next day due to such a narrow time room.

8.6.1.2. Cultural difference.

Cultural difference between Europe and Asian regions is extremely big (see figure 29). In fact eastern and western cultures are two distinct dimensions and before starting up intercultural complex technical project senior managers should ask themselves if they made any allowance for cultural constraints and their potentially negative impact on performance when planning future profits.

	West (US / Europe)	East (China / East Asia)
Logic	Linear (direct associations)	Spiral (roundabout)
Communication	Direct, verbal	Indirect, implied
Identity	Individual, independent	Group orientated
Agreement / Disagreement	Argumentative, verbal	Hard to say no, non-verbal
Punctuality	Start and end on time	Appointments flexible
Respect	Success, achievement	Seniority, wisdom
Business Relationship	Economics come first	Relationship comes first
Decision Making	Distributed, proactive	Manager has final say
Time Horizon	Short term (per quarter)	Long term (years ahead)
Risk / Spending	Risk-takers, spend	Risk-avoiders, save

Figure 29. Cultural difference between the Easter and the Western cultures (Randomwire, 2010)

8.6.1.3. Working conditions

Since Asian offices of Norwegian companies work in accordance with local labour legislation it has negative effect on project tasks execution. Compare to Norway where notice period for employees is commonly three month, for example, an Indian engineer is entitled to give notice only some weeks in advance. If the engineer is deeply involved in project activities on piping design tasks, then such a short period can be insufficient to hand over the job to the successor properly. Due to improper delegation of job it takes fairly much time for a new employee to adapt to new tasks, learning curve for him will be longer, besides it will be a high potential for messing up anything due to unfamiliarity with corporative principles, working systems and processes. Moreover management at region offices has often problems to find and employ a right candidate with relevant experience, as a result lack of a worker in Indian office can hinder or even interrupt project execution in Norwegian office of the company.

It is obvious that the given and similar situations give rise some uncertainties and tension and management should properly control these situation, otherwise it is relevant to expect design flaw so that PSIBs are at stake.

8.6.1.4. Communication issues

Communication is another issue for joint activity. Most of contacts between the Norwegian and the Asian offices happen through email, messenger and video conferences. It is not so easy to discuss complex technical and organizational question through writing. Video conferencing is another way of project communication, however the number of conference rooms is limited and booking is to be done in advance. Communication time is squeezed and many complicated questions should be discussed in fast way, when due to tension, some important fact can be forgotten, or lack of important piece of information make the conference time less effective.

8.6.1.5. Possible outcome of utilization of remote offices in Asia.

Before involvement foreign employees on remote principle, senior management should think twice. Management should be aware that due to such a change organization becomes more complex. Misunderstanding conditioned by cultural difference and communication problems often takes place in multicultural project environment. All this is complicated by limited time for cooperation due to time difference.
Special attention is to be paid to type of work delegated to foreign colleagues. Primary engineering activities must stay in the head office in Norway, while the remote office should serve a source of support. Obviously it is less sensible to delegate critical engineering activities requiring significant follow-up like complex piping system design and stress analysis. It is much more reasonably to give over less critical job like drawing production in order to decrease dependency upon remote workers, retain continuous control over PSIBs maintaining and keep communication to relevant level.

It is clear that abovementioned disadvantages can negatively effect on the M&M projects implementation and execution so that performance and safety are at stake. It is relatively easy to set directions for business development and achieving desired goals for smaller companies, or where employees work at least in one location, when informal discussions and direct supervision can be good tools to ensure that a project is being managed effectively, but when project organization becomes larger and more dispersed and spread a service provider becomes exposed to different risks, and also becomes less flexible and competitive.

Senior project management should understand that before attraction foreign specialists from the remote locations organizational drawbacks within the head office should be eliminated otherwise the company extension can worsen existing problems and prevent from proper alignment of remote office activity with the head organization. It should be kept in mind that there is a risk that saving on man hour costs will go at the expense of piping integrity barriers' performance thus it may come about that instead of extra income thanks to cost cutting, the service company will get a cost driver and decrease performance potential of the barriers required.

8.7. Management functions in PSIBs maintaining.

The abovementioned example demonstrates how irrelevant senior management decisions can negatively influence project execution and quality of delivered M&M services. It is only one of many examples where management actions, in different attempts of improvement, especially to make business more profitable, lead to disgusting results. M&M project organization is an extremely complicated and sensitive mechanism, comprising engineering, purchasing, fabrication, and installation and maintenance areas of activity. Weighting the priorities in favour of any single area of activity, not to mention excessive concentrating on profits, can easily undermine the organizational balance that is fairly difficult to achieve.

Undermined organizational balance can easily jeopardize creating, maintaining and improving of PSIBs. It is simply to comprehend if the reader refers to the structure of piping integrity barriers. The barriers consist of three constituents (see figure 30):

1. Hardware or piping system in our case.
2. Process (documented work practices and procedures)
3. People (personal skills and their application)

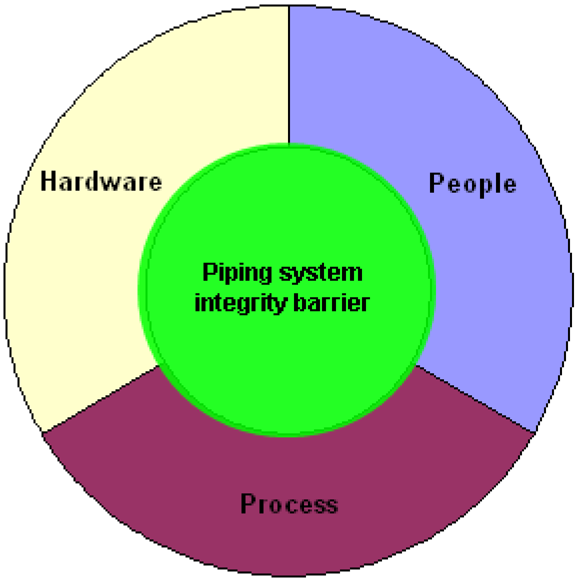

Figure 30. Structure of a piping system integrity barrier

So, it obvious that unfavourable and imbalanced M&M project environment can easily harm PSIB implementation, but, at the same time, it is clear that all three constituents of a PSIB are adjustable and can be controlled by management team. While the first component of PSIB, hardware, can be affected by managers indirectly, the two other components, process and people, allow management to exert direct influence on future performance and reliability of PSIB.

8.7.1. Hardware component of PSIB.

Hardware or pipework component of PSIB can be influenced indirectly by management in terms of selection of competent personnel to engineering positions. Management makes the decision about employment policy so it should be created favourable work conditions and perspective for career development to attract suitable personnel. Thus proper employment policy will contribute to how well the piping engineering tasks are accomplished in terms of PSIBs implementation, in cost effective manner.

8.7.2. Work processes for PSIB.

Experiences personnel employed by the company must have a chance to use skills by means of unambiguous work instruction and clear work processes. So, one of management's responsibilities is to create, update and verify work instructions and procedure, operational principles and management systems in accordance with continuously changing market conditions, authority regulations, client's preferences and corporative vision and strategy. PSIBs are governed by these work instructions and procedure, operational principles and management systems or, to be exact, included in them. Consequently, if managers loosen their hold on some of these important business regulating things PSIBs are at stake. PSIBs may become ineffective or obsolete. This relates to all the stage of piping system lifecycles.

Work instruction and procedures that were not updated in time may lead to selection of a concept for piping system, which is no longer valid due change of safety regulations. It might be that, due to lack of work instruction compliance with new standards, conventional PSIBs developed during the stage of detailed design of the piping system unexpectedly becomes insufficient or ineffective. It may be so that the M&M service providing company changes their operational principles offshore in order to please the customer needs without proper reflection of these changes at work governing documents, that can lead to numerous misunderstanding, delays etc, that immediately has profound impact on, critical MMO stage of the piping system life cycle and there is a risk to weaken performance and reliability of the PSIBs defined in the earlier stages of the piping system life cycle.

Work procedures should clearly define roles and responsibilities, both on engineering and MMO stages of the piping system life cycle for building and maintaining the PSIBs. Applicable work practices should take in account all hazard, relevant for the given process piping system, and are to be applied consistently. Procedures are to be clear enough to allow the users to identify the required steps and complete this steps in the right order and understand the plan of actions in case of abnormal or unexpected conditions.

8.7.3. Human factor for PSIB.

It is worth noting that without proper consideration of the human component, even the most sophisticated facilities are susceptible to loss of integrity caused by incorrect operations, unsuitable maintenance or de-motivated people (OGP, 2008)

It often happens that management's actions de-motivate people, like in case with utilization of Asian offices on the M&M projects, where new work principles gives rise by so many unexpected drawbacks. De-motivation comes up because management actions are often not sufficiently communicated to employees. They, in turn do not understand why they should do conventional and straightforward work tasks in a new, complicated and seemingly ridiculous manner, when many existing problems remain unsolved. The employees can see negative impact of Asian workforce inclusion in the M&M project execution and this cause de-motivation due to belief that management is not enough competent and hands-on if works in such a way. De-motivation is extremely negative thing in the company and may easily lead to employee's strong wish to change the employer. There is no full assurance that de-motivated employees will properly accomplish all required tasks, thus such a negative atmosphere on the M&M project can cause risks for all work flow and the PSIBs will undoubtedly be affected too. Hence management should always keep dialog with employees, communicate their ideas, motivate people to deal with challenges and try to address all incipient problems during the change processes.

Important role in PSIBs quality belongs to process safety culture among the employees. Ineffectiveness of process safety culture may be a common hole in multiple PSIBs, especially on MMO stage of piping system life cycle, that may lead to premature corrosion onset and fast damage of a piping system. Thus managers should encourage input from workers and provide adequate feedback for simplifying or improving the performance, reliability and ability of the existing asset integrity barriers (OGP, 2008).

As it was mention earlier in this thesis work, especially in the CUI chapter, right competence for a technical position is vital. Competences for a position or team are analogous to the performance standards developed for a hardware system (OGP, 2008). On M&M projects relevant competences are required by engineers, technicians offshore (construction, operations and maintenance) and, of course, technical authorities, supervisors and managers.

Competent personnel can make the difference between perfect performance and major accidents. So, competence for each position should be managed as follows (OGP, 2008):

- Identifying the required competence
- Providing relevant training (knowledge and skills)
- Assuring or verifying these competences (ability to apply knowledge and skills)
- Refreshing competences as appropriate.

The figure 31 illustrates disposition of piping system integrity barriers throughout piping system life cycle to withstand corrosion through so-called Swiss Cheese Model. Here each slice of cheese represents a piping system life cycle stage. The blue boxes below represent some of the barriers applicable to the given stage. The holes in each slice represent weaknesses of these barriers, both active and latent. Incident or, in our case, corrosion onset occurs when one or more holes in each of the slice align, permitting 'a trajectory of corrosion onset opportunity' so that hazard of corrosion passes through several barriers, leading to an incident (OGP, 2008).

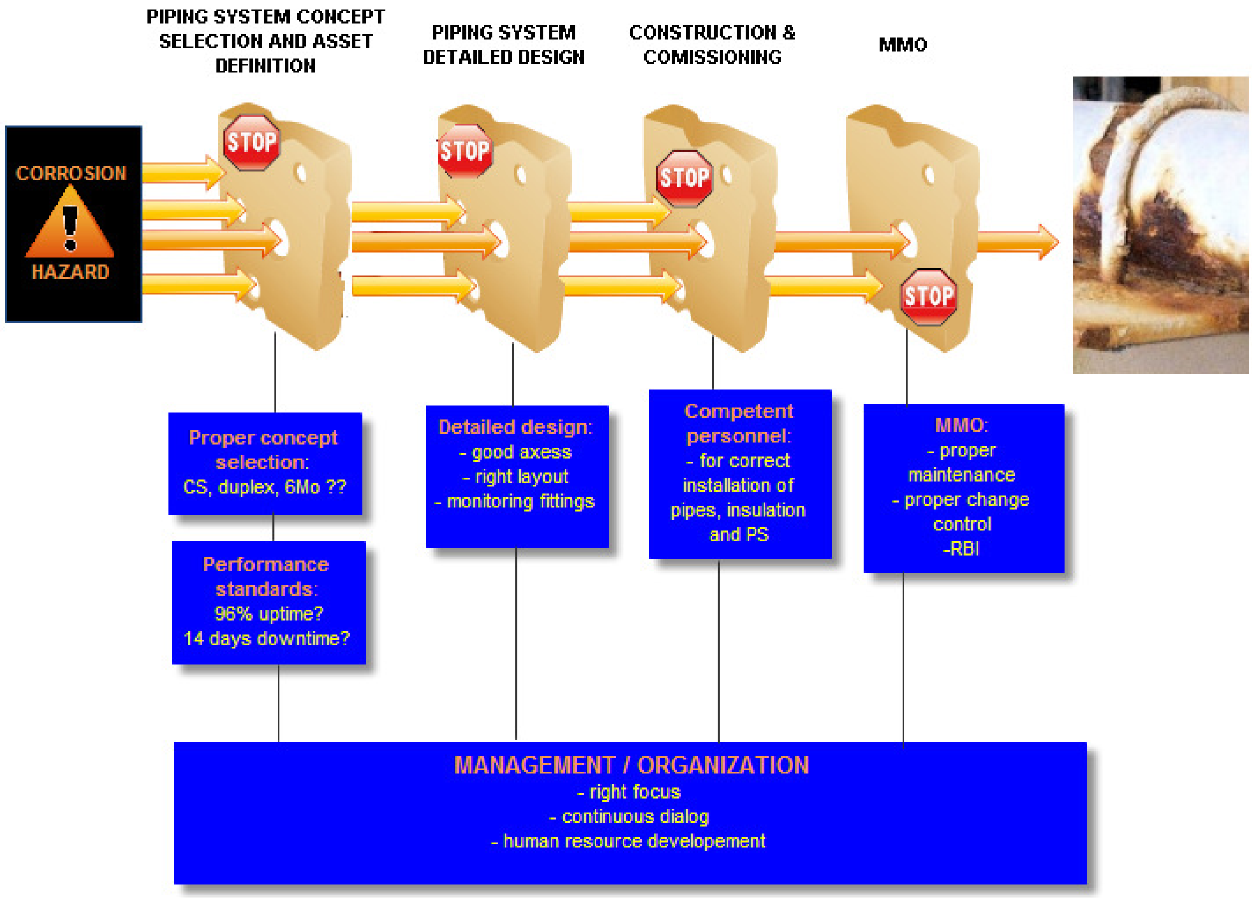

Figure 31. PSIBs throughout piping system life cycle (adapted from OGP manual, 2008)

For illustration of the situation where all the barriers fails, the following example can be given. The reader can imagine the situation where it was selected poor piping system concept, piping uptime was overestimated, piping and pipe supports detailed design did not consider maintenance needs and water-trapping possibility, the piping and supports were improperly installed and then maintenance was not fairly good. As a result the piping system developed tough outside corrosion so that replacement of pipes is required to avoid hydrocarbon fluid or gas leakage. The emphasis in this framework is placed on management – organizational barrier as the major barrier for sustainable, corrosion-free performance of the piping system.

9. Balancing organizational tensions.

It is normal for senior managers of service companies to seek profitable growth. For this purpose they have to innovate to be able to compete with other players. Sharing work with Asian office, presented earlier, is an example of such an innovation, here there is an example of new, potentially cost-effective way of doing internal task. Over time this innovation might turn into sustained profitability and growth, in spite of the range of inconveniences in the beginning. Nevertheless as experience shows an excessive emphasis on profit and growth can lead to danger. De-motivated employees may engage in behaviors that put the business at risk. They may misconstrue management's intentions and "innovate" in ways that present unnecessary risks to the company (Simons, 2000).

Simons (2000) underlines that a wise manager knows that control is the foundation for healthy business and only when adequate controls are in place managers can focus their energies on creating profit and only when business, in turn, profitable managers can focus on growing the business. Actually, constant tension between profit, growth and control is inherent in all businesses, including M&M services (figure 32).

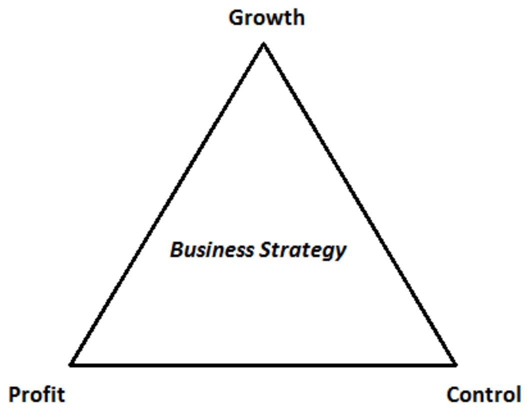

Figure 32. Tension of profit, growth and control (Simons, 2000)

Lack of adequate control can lead to collapse of a profitable M&M business. Moreover weaknesses of operational control inevitably results in errors and risk for operation. Simons (2000) is quite right when asserts that managers can fool themselves into thinking that because the business is profitable, controls must be adequate. It may be that business is still profitable now, but due to lack of control, the business can lower to breakeven point and further down.

According to the author's work experience on M&M projects the growth of project organization through sharing work with remote locations often happens when there is a lack of control and in main, domestic office in Norway. The control weaknesses are typically represented by range of performance killers:

- ***Strategy related performance killers*** (i.e. breach of contract due to excessively long delivery time leading, negligence and lack of control of known mistakes, poor planning, unaligned relationships with the client and subcontractors, too much documentation and details, etc.)
- ***Workforce and organization related performance killers*** (i.e. insufficient or irrelevant competence, unacceptable attitude and motivation, etc.)

In the author's opinion extension of project organization when having such serious drawbacks of domestic organization is a step towards further sending the organization into a tailspin. In fact, there is the situation when the company tries to minimize adverse effect of workforce costs by means of reducing man-hour cost through partly utilizing Asian engineers. Simultaneously the company management ignores problems at the domestic office represented by a set of performance killers. Since sharing work between Norwegian and Indian offices is a fairly tough and demanding process involving inherent particularities it is evident that under pressure exerted on the organization by the existing performance killers, the undertaking will scarcely thrive and sooner fail. Consequently an opportunity to improve performance can take opposite effect and become for organization an extra burden, which worsens performance even more.

The author of the research finds it fairly unprofessional when attempting to improve performance by utilization of quantitative methods instead of qualitative. Experience shows that quantitative methods are often ineffective and only postpone severe consequences for a company. Actually quantitative methods should be utilized in conjunction with qualitative, for instance a company attracts foreign workforce for reduction of labour costs and simultaneously optimize planning and alignment with clients and subcontractors. It is absolutely possible if management is hand-on enough and employees are properly orientated, like it is in Aibel AS.

Maskell (1991) states that 'many performance measures currently in widespread use are not only relevant, but make people do wrong things. In most traditional industries the actual labor content of a production step is measured and then overheads are apportioned based upon labor costs. A traditional approach assigns a disproportionate emphasis to labor costs, thus forcing managers to concentrate too much effort on reducing labor content. In reality, there are others far more significant issues they should be tackling – issues like quality, inventory levels, employee participation, on-time deliveries, and customer satisfaction. Traditional financial performance measures were not designed to address such aspects of a company's business, but yet remain the primary (and usually obsolete) method of performance measurement in most companies.'

10. Focus on wrong performance indicators

The abovementioned case with establishing Asian office for man-hour cost cutting while lacking control in domestic office along with Maskells (1991) findings indicates on totally wrong management focus on M&M projects. Management is still focused on financial performance indicators, unfortunately. In fact management of higher and lower level on technical, offshore M&M project is often represented by people without technical background, anything like accouters and financiers.

Once the author of the thesis had a situation where he had to explain his task lead the difference between an operating pipe and a pipe that is out of service, since the task lead did not have awareness about it and was going to initiate installation of new pipe supports on the existing vibrating, process pipes. Ultimately the task lead took the authors point, however it took him time to convince the lead that there were no sense to do so. Considering that the task lead was a middle-aged employee with background in <u>accounting</u> it took the author relatively little time to show the difference between two cases, hot and vibrating versus cold and still pipes. It is clear that PSIBs quality and reliability are at stake on both the design and commissioning stages of the piping system if the task lead does not have technical background, and potential risks here are much more serious than corrosion onset.

Another example of wrong senior management priorities is the following. Once the author, a pipe support engineer with 6 year technical experience, a technical bachelor grade, a technical master grade and another technical, quite relevant master study in offshore technologies in progress decided to apply an internal vacancy "Junior Project Engineer". He thought to be a fairly relevant applicant, considering his working experience, education and personal attitude to work known in the company. After about four month his candidature was rejected for the position. Later it became known that the candidate selected for the position was a pretty young person with a diploma in finances.

It is not surprisingly that non-technical managers with financial background are particularly concentrated on traditional, financial performance indicators at expense of relevant non-financial ones. But the author guesses it witnesses about absolutely wrong perception of M&M project delivery and poor state of affair in the company. M&M project is a complex organization that functions through continuous collaboration of numerous units on several levels, in fact there are four primary ones. The first level is an area of contacts between the service providing organization, client and subcontractors. The second level is an internal area which serves as interface array for engineering, project disciplines and management. The third project level is fabrication process of designed equipment. The fourth level is offshore related activities including equipment installation, commissioning, operation and maintenance. Moreover, these four levels are interconnected and continuously in communicating. So there is plenty of room for improvement and optimization in quality issues on all the levels, duration of operations and compliance with deadlines, client satisfaction, risk minimization and many others parameters which are to be of managements candidates for improvement other than man-hour costs.

Maskell (1991) precisely points out that over the last decades industrial techniques and technologies dramatically changed but accounting management stayed the same and unfortunately this tradition leads to company managers being misled because the accounting system is measuring the wrong things in the wrong way; also people are motivated to do the wrong things because they are endeavoring to achieve irrelevant targets. Maskell expressed these thoughts twenty one years ago and it looks so amazing to me that after two decades of unbelievable technological breakthrough the problem with disproportionate emphasis on financial performance measures still exists.

According to Maskell (1991) non-financial measure now are at least equal if not more important to the financial results and are the only measures used by the operational staff. The author indicates that 'financial measures remain important for external reporting, and there is still need to have cost accounts and the financial accounts integrated and consistent. But the day-to-day control of industrial and engineering processes is handled better with non-financial measures. The fundamental flaw in the use of management accounting reports for operational performance measurement is the assumption that financial reports are valid and relevant to the control of daily business operations. This assumption is wrong. Not only are financial reports irrelevant to daily operations, they generally confusing, misleading, and in some cases positively harmful to the business.'

Indeed, let assume that management of one of M&M service providers that runs a big project on mature big offshore platform, within 5 years frame agreement is very proud of their achievement. Why not to be proud? EBITDA indicators are not less than in average in the branch, what can be better for management? It would be better to cut labor costs, and then EBIDTA can be even higher! At the same time, a client, large operator is not so cheerful about project execution. Deliveries are often subject to delay, quality leaves much to be desired, communication is rather complicated.., in other words the client slowly runs out of patience and it seems that option for prolongation of the contract will barely be used, especially taking in consideration how carefully and rationally M&M services are rendered for another operators platform by another service provider. Undoubtedly the preference will be given to the second service provider, while management of the first one, proud of their results, will scratch their heads wondering what was wrong.

And Maskell (1991) one more time reveals obvious things, specifically 'if production personnel, supervisors, and management are to use performance measures to help achieve business strategy, the performance measures must directly inform them of success or failure. Reports must present the results of their efforts in terms that are relevant to their work and must not be disguised in financial figures.'

11. Information age competition principles.

It is accepted to consider that time span from 1850 to about 1975 can be related to industrial age, when following this period until now information age has been continuing. During industrial age it was vital for companies to utilize benefits of economy of scale and scope in order to prosper. The first priority for a company in order to succeed was ability to embed the new technology into physical assets offering efficient mass production of standard products. Financial control systems were created during industrial age for facilitating and monitoring ways of efficient allocation of financial and physical resources. One of important financial indicators such as return-on-capital-employed could simultaneously direct internal capital of a company to its most productive use and perform monitoring of the efficiency demonstrated by operating divisions which used capital for generating profits for shareholders.

When information age emerged many of the fundamental assumptions of industrial age competition became obsolete. After emergence of information era it got almost impossible for companies to get competitive advantages by means of rapid introducing new technology in physical assets and sensible management of financial resources and liabilities.

In order to secure for competitive success in information age service companies requires new capabilities. In the information age the most important ability for a service organization is reasonable mobilization and exploitation of its intangible assets, while investing and managing tangible assets pale into significance dramatically. Intangible assets make it possible for a service provider the following (Kaplan and Norton, 1996):

- Develop customer relationships that retain the loyalty of existing customers and enable new customer segments and market areas to be served effectively and efficiently
- Introduce innovative products and services desired by targeted customer segments

- Produce customized high-quality products and services at low costs and with short lead times
- Mobilize employees skills and motivation for continuous improvements in process capabilities, quality and response time
- Deploy information technology, data bases and systems

11.1. New operational environment on the NCS.

The Norwegian O&G market is a quite specific one compare to others. Even though information age competition is supposed to be commenced in the later 70th, relationship between the players of the Norwegian O&G market are still in transitional stage from industrial to information age competition, in the author's opinion. Or it seems like that the model of the Norwegian O&G market is represented by specific combination of features inherent to both industrial and information competition concept.

The Norwegian O&G market can be characterized by presence of a major, dominant player. This player is Statoil ASA, a Norwegian energy company, largest operator in Norway, with 67% ownership by the Government of Norway. Statoil ASA is operating about 80 % of producing O&G fields on the NCS. Such a solid market share was attained through affiliation of O&G assets of another company with the Government shareholding, Hydro ASA.

Until the Global Financial Crisis of 2008 – 2009 years Statoil ASA had traditionally been a preferred client for the Norwegian O&G suppliers. The main distinctive feature of Statoil compare to foreign operators like BP, Shell etc. was, in my opinion, tolerance to M&M service providers. If we refer to information age competition principles according to them clients have becoming more and more demanding in quality, cost, reliability, lead time and flexibility, Statoil could scarcely be called a typical information era client. That made Statoil an extremely comfortable and desirable client for suppliers, since numerous mistakes made by them repeatedly were forgiven.

The Global Financial Crisis which came in 2008 was a pivot point for all Norwegian O&G market. Due to global anticipation of consumption reduction oil price more than halved from historical record peak of 145 dollars a barrel. The fact of sudden and significant reduction of cash-flow and profits made operators working on the NCS, especially Norwegian ones to re-evaluate their philosophy towards performance and optimization improvement. The most suitable and relevant object for cost reduction was service suppliers.

For Statoil the Crisis and shrunk revenue became a suitable motive to exert pressure on the suppliers, which did not excel at high performance so far. The author recalls one article about Statoil which he came across in 2009, the article was about Statoil's discontent with quality of services provided to Statoil's offshore facilities. It was given an example where due to failure of one of the suppliers to read the drawings correctly, it was performed wrong modification. During this modification the facility was shut down for a period, then it took the same time to redo the task, so that losses for down-time, wrong modification and correction activity exceeded 200 mil. NOK. The service provider was fairly minor to cover the sum of expenses and Statoil had no choice but forgot about compensation and forgive a debt. There was not a single case of bad work performance, unfortunately. Thereafter Statoil issued a statement about unwillingness to pay too much for too bad quality. As a result Statoil switched from a tolerant and comfortable client to genuine, demanding, and information age inherent client, a client which reasonably started to derive benefit from being nearly a monopolist and dictate their terms to suppliers of M&M services.

There were some smart players among offshore service providers which always kept the portfolio of clients diversified, like IKM with the rule of no more than 20% share per client. However for majority of suppliers, oriented at Statoil this dramatic change in the rules of the game took serious effect. Since a client becomes an information age class client, suppliers should follow and catch up with successful suppliers of information era class to stay in business.

Important steps of Statoil were made with regard to M&M contracts. Both ongoing and new M&M contracts were reconsidered towards performance enhancement, including cost reduction and optimizations, stringent timing and flexibility. Besides it was introduced financial responsibility of service companies for non-compliance with contract terms, e.g. delay in delivery.

Changed rules of the game for M&M service providers reminded the author the concept of natural selection developed by Charles Darwin, which states that “adaptations contribute to the fitness and survival of individuals” (Wikipedia, 2010).

A proverb saying that every cloud has its silver lining is fairly relevant for this case. The Financial Crisis has played important role in healing of the Norwegian O&G market, since it has revealed the most effective players within the market. Some former leaders and giants, traditionally dominating the market turned out too clumsy and inflexible to reorganize themselves and adjust accordingly. At the same time it was a good chance for more effective and flexible service providers to make a name and increase their market share through winning trust and loyalty of the operators. When the Crisis was gone, huge excitement and optimism came up on the O&G market of Norway. As a result operators decided to invest serious funds in offshore modification projects, effective players were preferred and got new, big M&M contracts from both Statoil and non-traditional new clients like Shell etc.

To the author’s mind, post-crisis developments on the Norwegian O&G market can lead to not only “natural selection” of new effective players, but moreover general M&M supplier’s attitude to quality and reliability of rendered services should improve as well, since information age environment can be characterized by growing tendency to single or limited sourcing. In turn we have a chance to get sustainable working environment with reduced risk to people and assets. Thus criticality of operations on ageing platforms will be minimized.

11.2. Information age companies’ particularities

The abovementioned situation describing attempt to increase performance by man-hour cost cutting by means of sharing work with an Asian office without good order in domestic organization demonstrates an example of how a company tries to adjust to the new rules of the game after the Crisis. The company cannot be considered an information age class company, but makes first steps towards new quality. Further steps can be more sensible if management will keep in mind some new operating assumption on which information age organizations are built on. These assumptions are the following:

- **Cross-functions**. Industrial age organizations gain competitive advantage through specialization of function skills: in manufacturing, purchasing distribution, marketing, and technology. This specialization yielded substantial benefits, but, over time, maximization of functional specialization led to enormous inefficiencies, hand-offs between departments, and slow response processes (Kaplan and Norton, 1996). However, the author knows from his personal experience that some Norwegian M&M service providers still have maximized functional specialization. This method used to work so far, but no more. It is no longer useful because if a company strives to become an information age organization, one must operate with integrated business processes where traditional business functions are cut across. In information age organization speed, efficiency and quality of integrated business processes is smartly combined with the specialization benefits from functional expertise.

- **Customer segmentation.** Industrial age companies prospered by offering low-cost but standardized products and services, while information age companies must learn to offer customized products and services to its diverse customer segments, without paying the usual cost penalty for high-variety, low-volume operation (Kaplan and Norton, 1996). This principle is especially relevant for companies rendering M&M services for ageing offshore platforms where there is a big number of defects requiring special approach and non-standard and customized solution. A suitable example here is Statfjord A platform, mentioned earlier in the part describing technical aspects. Since the platform is planned to be decommissioned in around five years, but scale of wear is high enough, the operator, Statoil AS tries to reduce maintenance costs through wide utilization of GRE piping systems, which do not suffer from corrosion. M&M project is split into many relatively small tasks. Due to lead times and project's specific GRE piping material is ordered from different suppliers and each of them has own piping specifications. It goes without saying that service provider should properly deal with customized solutions to render services without penalties. Otherwise there is always a chance that work will be handed over to a smarter competitor.

- **Global scale.** Kaplan and Norton (1996) emphasize that "domestic borders are no longer a barrier to competition from more efficient and responsive foreign companies. Information age companies compete against the best companies in the world. Information age companies must combine the efficiencies and competitive honing of global operations with marketing sensitivity to local customers". This statement sounds like a warning for some Norwegian service providers which lag behind the global trend. The ratio of price to performance is not in favour of the latter. For example, gradually increasing number of drilling platforms and FPSOs ordering at South Korean shipyards by the oil companies operating on the NCS proves Kaplans point. Thus we can see that Norwegian service providers are involved in competition of global scale and it needs to take significant measures and efforts to reach Asian competitors, not to mention outstrip them.

- **People**. People in information age companies are greatly esteemed as the main intangible asset. One plant manager of Ford engine plant declared, "The machines are designed to run automatically. The people's job is to think, to solve problems, to ensure quality, not to watch the parts go by. Here, people are viewed as problem solvers, not variable costs" (Kaplan and Norton, 1996). Information age organizations encourage all employees to contribute value by means of their knowledge and information that they can provide. For the success of information age company it is vital to invest in, manage and exploit the knowledge of every employee

11.3. Improvement programs for organizations

In order to succeed in information age competition in future, organizations attempt to transform themselves by means of turning to improvement initiatives such as:

- Total quality management
- Time-based competition
- Lean production
- Building customer-focused organizations
- Activity based cost management
- Employee empowerment

All these improvement programs were successfully implemented so far. The programs compete for time, energy and resources. All these programs promise breakthrough performance and improved value creation for all interested constituencies: shareholders, customers, suppliers and employees. The purpose of these programs is continuous performance, providing success for a company in the new information age competition.

However, it should be noted, that in many case these programs failed to yield the expected result. The programs may not have only limited links to, say, organization's strategy or achieving specific financial and economic goals. In order to succeed in implementation of the improvement programs it needs to have a thorough, major change in an organization, when changes in the measurement and management system used by the organization will be a part of the major change. In my opinion, there are two major constraints, preventing the improvement initiatives from successful implementation:

1. Implementation of improvement programs fails due to lack of management's patience and determination to strive for success and not give up until the goals are accomplished. The author notes from personal experience that initially, especially after release of some financial reports demonstrating poor own performance or higher

performance of competitors, top management gets a sudden flash of inspiration. The managers calls a meeting where they communicate their vision of performance problems and possible solutions, and then they create and pronounce a performance improvement program, creating a spirit of change in organization and motivating employees to work on implementation. Everything goes well, and overall performance improvement atmosphere in a company plays its role and first results are yielded. Managers are very content and confident in future success of the improvement program. But gradually, in the mistaking belief that everything is perfect and under control, their attention to the process fades out. As a result, employees that cannot see or feel any interest to performance enhancement program from management deiced that the goals are achieved or it is no longer relevant for an organization, thus they cease to contribute to the program and finally a company contents itself with minor performance enhancement, often negligible on overall organizations scale.

Here the author would like to refer to Maskell (1991), that indicates significant challenges arising during implementing world class organization that match information age criteria. He asserts that it is unacceptable to confine such an important undertaking to simple policies setting and expecting employees to put these into practice. Considering that the changes required are extremely radical each organization attempting to achieve information age standard needs at least one senior manager with the vision, determination, and skill to see the task through to completion. The author describes this kind of leader as a champion and emphasize that all innovation companies must have people like this, or people with the drive to be the champions of changes and improvements.

The author cannot agree more with the Maskell (1991), since the failed improvements programs which he observed with great interest were spontaneously initiated, with dispersed responsibility and without a definite person leading the program. An improvement program should be considered as a real project with all elements inherent to a project, like budget, strategy, planning, risk and quality estimates, team building etc. A project should have a manager with clear understanding of the purposes and possible impact of project execution on organization. Only systematic and consistent approach to improvement program implementation can guarantee success of the program.

2. Another serious constraint to successful Implementation of improvement programs was already mentioned earlier in the thesis work, the author of the thesis means excessive management orientation towards financial measures. Kaplan and Norton (1996) point up the following: "Breakthroughs in performance require major change, and that includes changes in the measurement and management systems used by organization. Navigating to a more competitive, technological, and capability-driven future cannot be accomplished merely by monitoring and controlling financial measures of past performance." Implementation of all the new improvement initiatives and change in information age companies happens in environment which is governed by financial reports. However the financial reporting processes are still fastened to an accounting model developed in 19th century for an environment where arm's length transactions between companies existed. Such a type of a financial accounting model is still in use by information age companies when they build internal assets and capabilities and for development of linkages and strategic relationship with external partners.

Kaplan and Norton (1996) assume that extension of the financial accounting model to a certain degree could be highly beneficial. The authors suppose that ideally the model should incorporate the valuation of organization's intangible and intellectual assets, including high-quality products and services, motivated and skilled employees, responsive and predictable internal processes and, of course, satisfied and loyal clients.

Indeed, such a valuation of intangible assets and company capabilities would be quite beneficial, taking in account the fact that, intangible assets are by far more critical than traditional, tangible ones. However, it is quite difficult to place reliable financial value on such assets as process capabilities, employee skills, motivation, flexibility and customer loyalty.

11.4. Balanced Scorecard – way to sustainable development

Fortunately, situation is not hopeless and trade-off between values of industrial age and information age exists. The collision between the irresistible force to build long-range competitive capabilities and the immovable object of the historical-cost financial accounting model has created a new synthesis: the *Balanced Scorecard* (Kaplan and Norton, 1996). The *Balanced Scorecard* keeps financial measures. These measures tell the story of the past, the story which is relevant for industrial age companies those were not interested seriously in long-term capabilities and customer relationship. Financial measures are not good enough for information age companies involved in creating future value by means of investment in customers, suppliers, processes, technologies, and innovation. The Balanced Scorecard harmoniously combines financial measures of past performance with measures of the drivers of future performance. Organization's vision and strategy defines the objectives and measures of the scorecard, which view four perspectives of organizational performance: financial, customer, internal business process, and learning and growth. These four constituents provide the framework for the Balanced Scorecard (see figure 34).

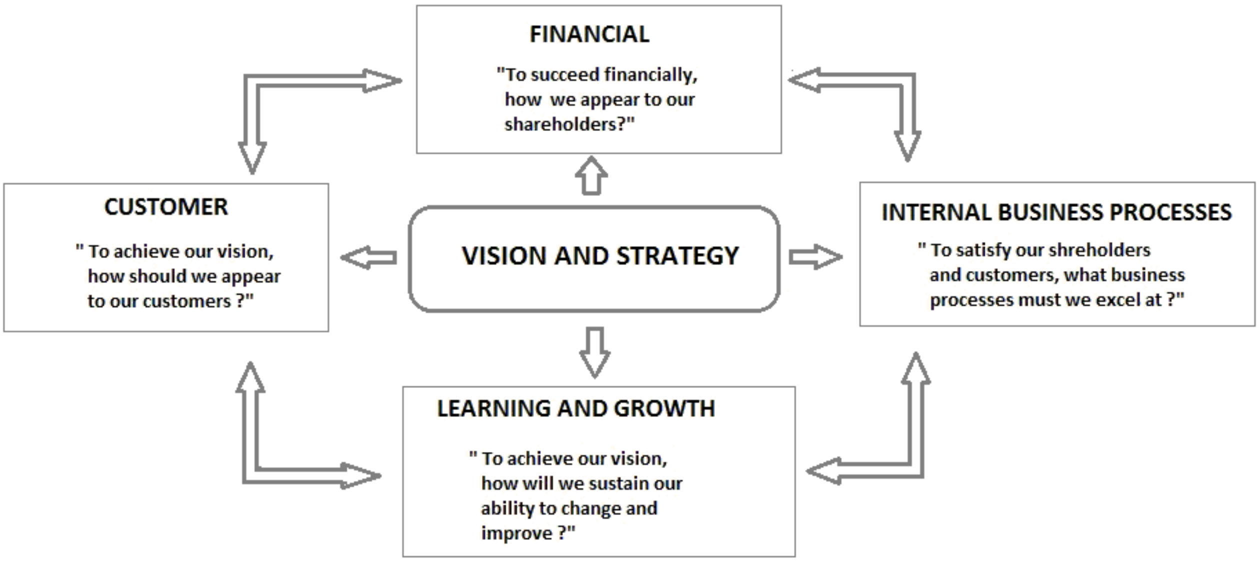

Figure 34. The Balanced Scorecard provides a framework to translate a Strategy into Operational Terms (adapted from Kaplan and Norton, 1996)

Using the Balanced Scorecard corporate executives become able to measure how their business units create value for current and future customers and what steps to be made to enhance internal capabilities and the investment in people, systems, and procedures important for improvement of future performance. By means of the Balanced Scorecard the critical value-creation activities created by skilled and motivated organizational participants can be captured. Retaining focus on short-term performance, through the financial perspective, the Balanced Scorecard uncovers the value drivers vital for superior long-term financial and competitive performance.

In fact, many organizations use financial and non-financial measures, however they use them only for tactical feedback and monitoring of short-term operations. The Balanced Scorecard underlines that financial and non-financial measures must be a part of the information system for all employees irrespective of level in the organization. Front-line employees must comprehend which financial impact their decisions and action can have, at the same time it is required strong understanding of the long-term financial success drivers by senior executives. For the Balanced Scorecard the objectives and the measures is not just a situational collection of financial and non-financial performance measures. These measures are derived from a top-down process which is forced by the mission and strategy of the business unit. A business unit’s mission and strategy should be translated into tangible objectives and measures by the Balanced Scorecard.

Kaplan and Norton (1996) point out that “the measures represent a balance between external measures for shareholders and customers, and internal measures of critical business processes, innovation, and learning and growth. The measures are balanced between the outcome measures – the results from past efforts – and the measure that derives future performance. And the scorecard is the balance between objective, easily quantified outcome measures and subjective, somewhat judgmental, performance drivers of the outcome measures.”

It is extremely important and relevant that the Balanced Scorecard is not just a tactical or an operational measurement system. Scorecard is used by innovative companies as a strategic management system, for managing their strategy during their long run. Innovative companies use the measurement focus of the scorecard for accomplishment of critical management processes and Kaplan and Norton (1996) accentuate some of them:

1. Clarify and translate vision and strategy
2. Communicate and link strategic objectives and measures
3. Plan, set targets, and align strategic initiatives
4. Enhance strategic feedback and learning

In other words, the Balanced Scorecard will assist and guide mangers of M&M projects in adoption of the framework for development of a performance based service strategy. The Balanced Scorecard can help M&M service provider to spread and allocate adequate attention and efforts through all the areas of importance. So that evident imbalance between financial and non-financial measures can be eliminated. The Balanced Scorecard application will strengthen adherence to principles of continuous learning, improvement and reassessment. Besides, through equally strong focus both on customers and internal business processes, The Balanced Scorecard will continuously monitor quality of alignment between supplier's service delivery strategy and customer's service receiving strategy. The BS can helpful and powerful tool capable of increasing a service provider's efficiency, effectiveness and competitiveness. Right balance in focus between tangible and intangible assets supports a service provider during both project's service strategy implementation which include allocation of resources, defining budgets, distribution of human resources, building organization, defining activities and tasks. As a result of the BS application M&M service provider minimizes gap between required and actually delivered services.

The Balanced Scorecard seems to be an especially valuable tool in context of critical tail-end phase of the field in conjunction with state of ageing platforms. Taking in account relative inflexibility of conventional M&M contracts the Balanced Scorecard can contribute to development of adaptability of the latter to customer's changeable needs, besides through better employment of resources by a service provider on the ageing production facilities its operational performance can substantially raise. Use of the BS by supplier brings about more order and predictability in operations and thereby wins operation loyalty satisfaction. This, in turn, stimulates sustainable and safe cooperation.

12. Discussion

The research of piping integrity problems on ageing platforms, on the NCS over M&M projects execution yielded some important findings:

- **Corrosion under insulation (CUI).** It was discovered that "highest incidents of leaks in the process piping are due to CUI but not inner process corrosion" and moreover from 40 to 60 percent of piping maintenance costs are related to CUI.

- **Pipe supports related corrosion.** Pipe supports can cause serious corrosion problems for process piping due to ability to trap water at pipe support points so that paint system fails and corrosion starts. Despite the known fact that this corrosion is induced by water trapping many operators, including Norwegian ones, still mistakenly believe that the problem is metal-to-metal contact between pipe support structure and pipe. This misconception prompts the operators to approve the solutions against metal-to-metal contact corrosion, however the turn out to be counterproductive and causing intensive piping corrosion.

- **Material for process piping.** There are many material alternatives for process piping, on the market. These materials have different properties and price so that each industrial client can select required, specific solution applicable for each unique project with different demand for price, durability and corrosion resistance.

- **Stainless steel (SS) piping.** Contrary to popular belief stainless steel piping is subject to corrosion in saline, marine environment, offshore. Corrosion rate for SS is higher in warmer water.

- **Glass reinforced epoxy (GRE) piping.** GRE technology is very popular technology, attracting operators by corrosion free performance. Nevertheless there are some unfavourable facts about GRE piping which should be taken in account by operator before selecting piping concept, which include low impact resistivity, sensitivity to handling, excessive flexibility, sensitivity to mechanical vibrations, micro-structural quality issues and long-term behavior uncertainties.

- **Piping vibration caused by modification on M&M projects.** Corrective maintenance tasks of M&M project often involve partly replacement of corroded piping spools, so that the renewed piping system includes both old CS spools and new SS spools. Because of difference of properties and wall thickness of the materials, a new stress state comes up within the renewed piping system. Due to this, significant piping vibration often comes up, since sometimes stress analysis for the altered system is drop in mistaken belief that system remains unchanged if routing stays the same.

- **Piping system integrity barriers (PSIB).** PSIBs can be provided at all the stages throughout the piping system lifecycle, both at design stages and maintenance stages. Hence the piping system has quite high chances to avoid corrosion onset and other integrity deficiency, provided that PSIBs were developed decently.

- **Foreign workforce.** Because of intensified M&M service activity on the NCS and shortage of specialists locally, there is a growing trend towards employment of specialist from abroad. This relates to both white collar and blue collar workers.

- **Asian branches.** Some Norwegian M&M service providers establish branches in Asia in attempt to cut man-hour costs through use of local Asian specialists, which collaborate with Norwegian employees remotely on M&M projects.

- **Organizational tension.** It often happen that senior management seeking to make more profits, expand M&M project organization, making it more complex etc. without required adjustments. As a result, the organization becomes less flexible and controllable.

- **Function of senior management for PSIB maintaining.** Management barrier is vital for PSIB maintaining and implementation throughout lifecycle of a piping system. PSIB's structure, consisting of hardware, process and human constituents, is fairly adjustable and controllable by management team.

- **New operational environment on the NCS.** After the Financial Crises of 2008-2009 years the Norwegian O&G industry stepped into the phase of business relations, even more resembling information age relations, where performance and customer orientation are key qualities for successful business running.

13. Conclusions

The research of piping integrity problems on ageing platforms done for this thesis work lead the author to the following conclusions:

- Even though there is a wide choice of advanced, corrosion-resistant materials and technologies for process piping and pipe insulation, it does not give a guarantee of corrosion-free operation, unless these supreme technologies are relevant in the giving operational context. Only careful consideration to specifics of the project makes sure the maximum performance of the technology/material in cost effective manner.

- Quality of insulation system installation has primary importance to a piping system integrity and integrity barriers performance. The fact of use offshore workers with language problems for ISS (insulation, scaffolding, and surface protection) disciplines indicates on unacceptable corner-cutting and will undoubtedly have negative consequences for the future, operational stage of the piping system lifecycle and threat to piping integrity due to defects of insulation installed.

- Right piping system integrity barriers provided on earlier design stages in conjunction with proper installation of piping, pipe supports and insulation can significantly influence performance on the operational stage of the piping system lifecycle. The properly developed barriers can reduce maintenance activities to minimum, maintaining the integrity of the piping system with potentially lower OPEX level.

- Right piping system integrity barriers provided on the operational stage of ageing piping system enables to mitigate detrimental effects of possible fatal design flaws related to 70^{th}-80^{th}, when design is based on practices and regulations that turned completely obsolete by now.

- International, multicultural M&M projects especially performed at geographically spread locations have many particularities. They have big potential for cost cutting and at the same time, there is a strong need for numerous alignments and adjustments on these projects, not to mention increased complexity of relations and work processes during project implementation and execution stages. In other words, these projects are extremely challenging and demanding, and before starting them senior managers should consider all potential risks and estimate their strength to accomplish such an undertaking in best possible way. Otherwise the project can easily become a cost-driver and extra burden for a company.

- Attempts to increase M&M project profits through cutting the costs without enough efforts to improve work processes and employee's attitude can have opposite effect since growth of low effective organization can lead to even more disorder, which can finally collapse the business

- Altered rules of games in Norwegian O&G sector give a chance for more flexible and customer orientated players of M&M market to move less effective competitors and gain extra market share.

- Excessive concentration of M&M service providing companies' management on financial aspects other than on non-financial ones indicates on wrong attitude and perception.

- Process piping integrity problem is a topic of a great concern for operators. Even though there is more than enough advanced technologies to withstand piping integrity problems at competitive price, it is still poor progress in solving of the problem. The author of this thesis work is inclined to think that lack of the progress can account for shortage of competence needed for proper execution of M&M projects. The latter is aggravated by poor work processes along with employees' culture and attitude etc. There are problems which remain unsolved for years on M&M projects.

It is honest truth that M&M service rendering is extremely complicated and sensitive business, demanding significant efforts to arrange, adjust and maintain numerous business processes, nevertheless there are M&M service providing companies demonstrating perfect performance both financial and non-financial in conjunction with profitable growth. This example prompts the author to conclude that success strongly depends on management.

Since senior managers on M&M project often come from non-technical disciplines. All they have own perception of project execution and performance in accordance with background and competence. Considering the fact that many managers of different level have financial background it is not surprisingly if they are concentrated on financial performance, without deep understanding of crucial technical aspects of M&M services, so that evident drawbacks of work execution problems are out of their interest.

The author supposes that it must be present a special mechanism in M&M service companies which makes sure that only employees with relevant technical background competence can be selected for key management positions on the project. This will undoubtedly enable significant improvements in M&M project execution.

However, it worth noting that financial performance is equally important for M&M service provider and should never be ignored. Relation with customers and abilities of the company to learn and grow are vital for M&M service companies too. Thus it is must be applied a management system that is capable of distributing management efforts evenly, without disproportion. The Balanced Score card is perfect example of such a management system.

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