ABSTRACT

The system with a low level of reliability of being deployed in a cold climate often needs special and additional focus on maintainability characteristics in order to achieve the higher level of productivity, system availability and safety. Therefore, the maintainability issue is critical for the successful and effective operation of oil and gas installations in the Arctic environment as the working conditions are made very difficult by low temperature, ice, short period of daylight and lack of support facilities. Furthermore, the maintenance tasks or maintainability in the Arctic region is heavily influenced by the design of the task and the design of the equipment being maintained. The risk of human error in the Arctic environment is very high and about 80% of offshore accidents are caused by humans, with 64% occurring during operations. Moreover, human factors/ergonomics is now recognized as a major contributor to operational safety, loss prevention and optimizing system performance in the oil and gas industries. Therefore, the study of human factor and reliability is essential to ensure the safe and reliable operation of industrial plant and systems which involve human operators. Human factors’ integration aims to 'design-in' the humans into plant and system design, taking account of their capabilities and limitations. This can lead to significant savings through appropriate manning levels, maintainable plant, reduced rework and user-friendly facilities and systems.

The objective of this paper is to explore potential risk factors especially in Arctic conditions with a view to how human factors/ergonomic principles can help to reduce risk factors and increase maintainability of the oil and gas industry. In this paper, the starting point is the offshore oil and gas industry, but the methodology and discussion are to a large extent general and could also be applied in the other industries.

Key words: Cold environment, oil and gas industry, maintainability, ergonomics
In this situation, maintainability is carried out to minimize downtime and improve the performance of equipment. The purpose of the maintainability concept is to increase the efficiency and safety, as well as reduce the cost of equipment maintenance, given standard procedures and resources in different conditions. It should be noted that systems are often designed, built, and tested in an environment with moderate conditions such as a comfortable temperature and good lighting. However, in real life, environmental conditions, geographical distances, and human factors can be radically different from the manufacturing and testing conditions. For these concerns, the actual operating situation needs to be taken into account when designing for maintainability. Furthermore, due to the complexity of machine systems, and the environment conditions, it is often difficult for maintenance and service personnel to physically access all the system components, which makes it hard to perform the tasks within a prescribed period of time. This working situation may lead to psychological and physical stresses, but also to accidents that result in injuries and long-term sickness.

Such unwanted consequences have economic implications for the organizations that provide maintenance and services, as well as for their industrial customers and for society at large. Often, negligence in maintenance leads to unavoidable disastrous failures leading to loss of lives and assets. There is little doubt that human error contributes to the majority of incidents and accidents which occur within complex systems. Therefore, according to Blanchard et al. (1995), maintainability requirements include (1) considerations during the overall planning and documentation for any program or project; (2) top-level specifications for the applicable system/product; (3) iterative design process of functional analysis, requirement allocation, trade-off and optimization, synthesis, and component selection; and (4) measurements of system adequacy through test and evaluation. The basic process is illustrated in Figure 1.

However, the maintainability issue is critical for successful and effective operations of oil and gas installations in cold environments. The working conditions are made more difficult by low temperature, the presence of ice, the short period of daylight and the lack of support facilities in the northern areas. The maintainability performance in the Arctic region is heavily influenced by the design of the system components and of the maintenance support performance. Systems with low levels of reliability in a cold climate often need special and extra focus on maintainability characteristics in order to achieve the desired levels of productivity, system availability and safety. Equipment that is difficult to maintain, or components that can be incorrectly fitted, will contribute to maintenance errors which in turn may lead to lengthened repair time. Furthermore, equipment that is not designed to be error-tolerant can result in undetected faults when they occur. The costs associated with accidents due to human error can be staggering.

Workers who perform daily routine work outdoors during the harsh winter have been reported to have decreased performance and increased discomfort (Virokannas, 1996). Cold exposure and the associated behavioral and physiological reactions have an impact on human manual performance (Holmér et al., 1998). Manual performance is a combination of many
kinds of ability that require, for instance, good tactile sensitivity, hand dexterity, force capability and motor coordination, and these skills are all influenced by hand cooling (Geng et al., 2000). Therefore, cold environments have a direct impact on maintainability and maintenance support performance by the personnel (see also Markestet, 2008a, 2008b). According to the literature survey there has been yet no study found regarding the maintainability issues for equipment design in the Arctic environment considering ergonomic factors. Therefore, the purpose of this paper is to present and discuss maintainability issues and to recommend the possible solution for the improvement of maintainability in a cold environment by implementing ergonomics knowledge.

2. UNDERSTANDING THE BASIC CONCEPT
There are many cold, engineering and ergonomic issues that need to be understood prior to a guideline being developed for operation and maintenance in Arctic conditions. These issues are stated below.

2.1. FACTORS INFLUENCING PERFORMANCE IN THE COLD
There are many workers throughout the world who work in cold environments. A cold environment can be defined as an environment under which greater than normal heat losses are anticipated and compensatory thermoregulatory actions are required (Holmér, 1994). Exposure to cold commonly occurs in fields such as construction, agriculture, roadwork, fishing, forestry, oil and gas exploration, seafaring, mining, reindeer herding and rescue services (Piedrahita, 2008). In the northern part of Norway, some of the important operational environmental factors include temperature, wind, darkness and icing (Larsen & Markestet, 2007). Due to the warm ocean currents, the Barents Sea has a climate which is much milder than comparable areas at the same latitude. This applies particularly to the sea and air temperature, but in the winter the conditions are more hostile than at other parts of the Norwegian Continental Shelf. The working conditions will be difficult under such temperatures and equipment, materials and maintenance activities must be adapted to these conditions (Gudmestad & Strass, 1994).

There have been number of studies into the effect of cold on manual performance and there are clear findings that performance decreases (e.g. Hues et al., 1995; Kim et al., 2007). The behavioral and physiological reactions are associated with cold exposure and have an impact on human performance, i.e. manual, muscular and aerobic performance, simple and choice reaction time, vigilance, cognitive task etc. (Holmér et al., 1998). Generally, the effects of cold on performance are of two kinds: the peripheral effects, which influence strength and manual dexterity (Giesbrecht et al., 1995) and central effects which influence cognitive performance (Thomas et al., 1989). Here, manual dexterity can be defined as a motor skill that is determined by a range of motion of arm, hand and fingers and the possibility to manipulate with hand and fingers (Havenith and Dannen, 1995). It is known that exposure to the cold results in a decrement of physical and cognitive performance (Ellis et al., 1985; Giesbrecht and Bristow, 1992). The performance of complex tasks is more affected by cold than the simpler tasks (Enander, 1987; Thomas et al., 1989). Oska (2000) reported that cooling has a negative effect on muscular performance such as endurance, force, power, and velocity and coordination.

When a person is exposed to the cold and his metabolic rate is insufficient to maintain the neutral heat balance, the body will be cooling down, which leads to a reduction in blood supply to extremities and causes “physiological amputation” with extremity cooling (Havenith et al., 1995). A decrease in skin blood flow causes a loss in sensitivity and reduction in manual dexterity and grip strength (Vincent and Tipton, 1988; Parsons, 1993). Of all the parts of the body, the hands/fingers are among the most probable locations for cold stress related to thermal discomfort (Geng, 2001). The mobility of hands/fingers is associated
with the mobility of joints. When the body is exposed to the cold it causes the synovial fluid to be more viscous which causes slower movement. This phenomenon is called joint stiffness and when it increases, more muscle power is needed to make movement which might lead to musculoskeletal injuries (Geng, 2001). Therefore, the loss in manual performance in the cold may lead to inefficient work and an increased number of accidents and other complaints (Enander et al., 1979).

2.2. OUTCOMES OF EXPOSURE TO COLD
From the above review, it can be stated that working in the cold has an adverse effect on human performance which is summarized below:

- Reduced manual skills, dexterity, coordination and accuracy with an impact on productivity and safety.
- Increased risk of musculoskeletal injuries from stiffness of muscles and joints and reduced peripheral circulation.
- Increased risk of accidents from reduced alertness, manual dexterity and coordination.
- Discomfort from cold stiff hands and feet, runny nose and shivering
- Impaired ability to perceive cold, cuts, pain and heat.
- Reduced decision-making ability.

2.3 COLD-PROTECTIVE CLOTHING
To overcome some of the cold-related problems, adequate cold-protective clothing is necessary. The protection required in a cold environment often necessitates garments consisting of several layers of heavy insulating materials which affect physical performance which, in turn, is measured in terms of energy cost (Dorman, 2007). A study by Murphy et al. (2001) reported that the use of heavy clothing of 9.3kg resulted in increased energy cost and increased physiological and psychological demand when performing tasks for a longer period. Duggan (1988) suggested that increased energy cost is associated to the “hobbling effect” generally caused by the bulkiness and stiffness of clothing interfering with joint movements.

2.4 ILLUMINATION
The lighting available for visual inspection tasks can influence performance and productivity significantly. Improper illumination can make the discrimination of a defect difficult due to shadows, glare or too much or too little light. An inspection job that requires constant poor working posture to enable the maintenance personnel to get a good view of the component or equipment produces static muscle fatigue and can interfere with visibility. The maintenance personnel might have to bend over some obstacle to get close enough and could cast shadows on the surface or component being inspected and this may result in muscular fatigue and poor maintenance due to poor visibility. Yeow and Sen (2000) reported a project where ergonomic adjustment of the inspection workstation resulted in improved productivity by 6% and also resulted in a reduction of returned products from 12% to 4.5%. One study, carried out by Seminara and Parsons (1982), indicated the higher variance of illumination level in a nuclear power plant.

2.5. MAINTAINABILITY
Maintainability is formally defined as: “the ability of an item under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources” (IEV 191-02-07). It measures the ease and the time with which a system can be restored to an operational level after failure. The objective of the maintainability input is to minimize the maintenance time and labor hours considering design characteristics such as accessibility,
standardization, interchange ability, standardization of tools, etc. Measures of maintainability are generally related to the distribution of time needed for the performance of specified maintenance actions. For example, if a particular component has 90% maintainability in one hour, this means that there is 90% probability that the component will be repaired within an hour, given the desired tools, skill, education and environment. In order to increase maintainability, the repair time must be reduced in some manner. There are several key concepts that should be followed as part of any design activity that supports this reduction. The inner circle in Figure 2 identifies inherent maintainability design features, and the outer circle lists secondary features that affect the determination of the total system downtime. Secondary factors affecting maintainability focus on the maintenance and supply resources necessary to support the repair process. Establishing and maintaining the proper levels of these resources is often considered part of the logistic process.

Figure 2: Inherent and secondary maintainability design features (Ebeling, 1997)

In general, important factors influencing maintainability are stated below:

- **Standardization**: to what extent is the part a standardized element?
- **Interchangeability**: can the part be exchanged without any modification?
- **Accessibility**: what has to be done to gain access to the part?
- **Special tools**: what special tools are needed to work/remove/install/diagnose/test?
- **Removal/installation**: what has to be done to remove/install the part?
- **Mounting-proof**: what can be wrong-done/forgotten during removal/installation?
- **Safety precautions**: what safety precautions have to be taken?
- **Ease of handling**: can equipment be handled easily?
- **Troubleshooting**: how is the defect localized and detected?
- **Skill level**: what skill level is required to maintain the part?

2.6. ERGONOMIC ISSUES IN MAINTAINABILITY

Ergonomics is a multidisciplinary activity striving to assemble information on human capabilities and limitations and to use that information in designing jobs, products, workplaces and equipment. The terms ‘ergonomics’ and ‘human factors’ are sometime used synonymously. Ergonomics, however, has traditionally focused on how work affects the human. This focus includes studies of, among other things, physiological responses to physically demanding work, environmental stressors such as heat, cold, noise and illumination and so on. The emphasis has been on methods to reduce fatigue by designing tasks so that they fall within the human’s work capacities. Most often in the development of maintainability requirement, emphasis is placed on technical parameters related to
maintenance frequencies and time duration, and the associated logistic support, while the human element of the process is ignored (Blanchard et al., 1995). To optimize maintainability effectiveness efforts, the human element and its interface with the equipment needs to be addressed. Figure 3 shows the relation between maintainability and ergonomics.

![Figure 3: Relation between ergonomics and maintainability.](image)

When maintainability requirements are being established, particularly with regards to the human element, the relevant dimensions of the human body, its sensory ability, the environmental stresses that are likely to impact its performance, and the often important emotional aspects, must be considered. For example restricted reach to machine, temperature beyond the comfortable range of 12-22°C, noise outside the comfortable intensity level range of 50-80 db, or confusing color codes and maintenance procedures are likely to increase the probability of maintenance-induced failures. According to Blanchard et al., (1995), in general, human engineering must consider ergonomics factors such as:

**i) Anthropometric factors**: Anthropometric factors deal with measurement of the human body such as stature, sitting height, shoulder height, eye height, hand length, forward reach, wrist circumference, force, weight and so on. Anthropometric data are used in ergonomics to specify the physical dimensions of workspaces, equipment, furniture and clothing to ensure that physical mismatches between the dimensions of equipment and products and the corresponding user dimensions are avoided (Bridger, 2003). While establishing and implementing maintainability requirements, the anthropometric parameter should be taken into account. These parameters are especially important in designing test and support facilities and equipment, influencing the design of the major equipment itself for increased maintainability, delineating the maintenance procedure and activities that involve access to an embedded system component. The design engineer must also consider dimensions relative to both males and female, and take into account the appropriate variability. For example, if we take the smallest female and the tallest male in the population, the male will be 30-40% taller, 100% heavier and 500% stronger (Grieve and Pheasant, 1982). Body size and proportion vary greatly between different populations; if equipment was designed to fit 90% of the male US population, it would fit 10% of Vietnamese and 25% of Thais (Ashby, 1979).

**ii) Human sensory factors**: The human sensory capacities are sight, hearing, smell, feel or touch, and so on. In the design of test and diagnostic work centres, consoles, monitors, and read-out devices, the design engineer must be cognizant of the human capabilities relative to sight as it pertains to horizontal and vertical fields of view, the detection of signals and objects from varying angles, and the detection of certain colours under varying degrees of brightness from varying angles. Sufficient illumination is important along with the field of view for satisfactory performance of tasks. Noise issues need to be addressed as well for increased operator comfort, productivity, and efficiency.
iii) **Physiological factors:** It is important to recognise the impact of environmental stresses on human performance efficiency. Here, stress refers to an external or environmental situation that leads human productivity to decrease, and includes issues such as high and low temperature, humidity, high levels of noise and vibrations in the vicinity where operational and maintenance activities are being conducted. The consequences of stresses are reduced sensory capacities, slower motor response, and reduced mental alertness, leading to increased maintenance-error probability.

iv) **Psychological factors:** The psychological factors relate to the characteristics of the human mind. The effectiveness of maintenance task completion is significantly impacted by personal motivation, initiatives, dependability, confidence and so on. Maintenance policies and procedures which are perceived as being difficult or complex, or a poor management and supervisory style, can lead to increased psychological demand, frustration and poor attitude towards the work. On the other hand, if the tasks are over-simple and monotonous, this could lead to a more casual approach to the job and a greater number of maintenance errors due to carelessness.

The above ergonomic factors are basically taken into consideration for any working environment and the effect of these factors on maintainability could be totally different while performing maintenance tasks in extreme cold conditions in northern areas.

3. MAINTAINABILITY ISSUES IN COLD ENVIRONMENTS

Maintenance downtime constitutes the total elapsed time required (when the system in not operational) to repair and restore a system to full operating status, or retain a system in that condition. The downtime can be divided into different parts as follows:

1. The time it takes to successfully diagnose the cause of the failure.
2. The time it takes to procure or deliver the parts necessary to perform the repair.
3. The time it takes to gain access to the failed part or parts.
4. The time it takes to remove the failed components and replace them with functioning ones.
5. The time involved in bringing the system back to operating status.
6. The time it takes to verify that the system is functioning within specifications.
7. The time associated with “closing up” a system and returning it to normal operation.

As discussed in the previous section, the environment condition - such as a cold climate -will have an influence on the different part of maintenance downtime. Table 1 presents maintainability issues in the Arctic environment due to the human-equipment interaction.

<table>
<thead>
<tr>
<th>Maintainability issues in Arctic conditions</th>
<th>Probable reasons due to cold exposure</th>
</tr>
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<tbody>
<tr>
<td>Increased inspection time or fault detection time</td>
<td>• Reduced physical mobility; reduced hand dexterity; decreased cognitive performance; reduced motor-coordination; bulky clothing; decreased human sensory performance due to the limitation of vision and hearing due to hats and hoods and improper illumination level.</td>
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<tr>
<td>Same as above</td>
<td>• Improper anthropometric consideration for body dimensions while working in cold environment. Cold-protective clothing increases the measurement of body dimensions.</td>
</tr>
<tr>
<td>Increased access time to reach failed component</td>
<td>Same as above</td>
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<tr>
<td>Increased removal time for failed unit</td>
<td>Same as above</td>
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<tr>
<td>Higher repair time</td>
<td>Same as above</td>
</tr>
<tr>
<td>Increased replacement time for failed unit</td>
<td>Same as above</td>
</tr>
<tr>
<td>Increased testing time to verify repair</td>
<td>Same as above</td>
</tr>
</tbody>
</table>
Therefore, several aspects of human-equipment interaction in maintenance work must be considered when trying to find solutions to problems caused by improper design characteristics of any equipment and these factors are (Imrhan, 1992):

1. **Visual access** – the ability of maintenance personnel to see what is being done, to see immediate surroundings in order to identify the possible dangers in the working environment.

2. **Physical access** – the ability of maintenance personnel to position or reposition the body or other parts of the body within the work environment in a better working or ergonomically viable posture in order to perform the given task, and the ability to manipulate working tools etc. within the environment.

3. **Physical mobility** - the ability of maintenance personnel to manoeuvre the body or part of it, often with tools, within the work environment in order to perform the maintenance task.

4. **Strength** - the ability of maintenance personnel to generate the right amount of muscular force via hand-tools and other equipment - under specified conditions - for manual tasks, without experiencing exertion.

5. **Muscular and physiological endurance** - the ability of the operator to maintain a certain level of performance for a certain period of time, while using tools and other equipment.

6. **Cognitive performance** - the ability of maintenance personnel to perceive and process information mentally from the maintenance environment, and to decide on actions to be taken. Therefore, the instruction manual, arrangement and design of equipment, and so on can determine the speed and accuracy of the personnel.

7. **Education and training** - the ability of maintenance personnel to perform tasks successfully. This requires the ability to comprehend written and other instructions from maintenance manuals and to apply them to tasks. Education and training leads to reduction of mistakes by maintenance personnel.

8. **Safety** – this is a vast area, but it involves the ability of maintenance personnel to use the equipment and perform the given maintenance tasks without exceeding their cognitive, mental and physical limitations.

**4. DESIGN FOR MAINTAINABILITY IN ARCTIC REGIONS**

In this section, mainly design related issues have been discussed for the improvement of maintainability; other factors have also been stated which are briefly described.

**4.1. EQUIPMENT MAINTAINABILITY**

The most common complaint reported by maintenance personnel was the lack of easy access to the equipment requiring maintenance attention (Seminara and Parsons, 1982). Inaccessibility to equipment or components is associated with the placement of components in such a way that maintenance personnel find them unreachable and far beyond their visual limits for inspection purposes. In interview after interview, the proper access to the equipment by maintenance personnel was rated as a major obstacle and key issue for effective maintenance, and it was also found that 30% of savings in overall maintenance time could be achieved if proper access to equipment was made (Seminara and Parsons, 1982).

A large number of failures during operations, or low availability of a system, may be an indication that equipment may not have been properly maintained or designed. Poor maintenance could be identified from the cost of maintenance. Poor equipment design can increase the time taken to perform maintenance tasks. High rates of accidents and injuries may also indicate problems with the use and design of equipment (Imrhan, 1992). Therefore, for operation in northernmost regions, the oil and gas industry must consider the ergonomic design of equipment at the primary stage in order to reduce the maintenance downtime. The
cold conditions will double the impact on the maintenance personnel by restricting their ability to reach the equipment and parts of components as compared to a normal environment. The equipment should be designed in such a way that it should provide easy access for disassembly or assembly while working with cold-protective clothing such as gloves. This will result not only in decreased maintenance time but it will also enhance safety and job satisfaction.

4.2. FACILITY DESIGN FOR MAINTENANCE

Most of the oil and gas platforms or facilities were designed about three decades ago, when they accommodated a certain number of personnel. Now, demand for production is continuously increasing and at the same time the number of people has also increased in order to fulfill demand. A study carried out by Seminara and Parsons (1982) reported congested workshops in a nuclear plant due to the increased number of maintenance personnel. The other problem encountered in the layout of the facilities, was the placement of equipment and components in a location that was inaccessible from a normal work position. In the same study it was found that the maintenance organization had made strong efforts to overcome the initial design deficiencies. When considering the operation of oil and gas platforms in an Arctic region, the facility design must take ergonomic factors into account in the initial stages, including the workers’ anthropometric measurements when wearing cold-protective clothing, their physiological performance in the cold, their visual access, their cognitive performance, and the placement of equipment.

In the past, designers have usually ignored or underestimated the consequences imposed by protective clothing and the limiting impact of such clothing on manual dexterity, field of vision, and reduced cutaneous sensitivity (Seminara and Parsons, 1982). The improved facility design will increase visibility and reduce improper working posture while accessing the component which, in turn, will cut maintenance downtime and increase safety at the worksite.

4.3. ERGONOMICS GUIDELINES FOR MAINTAINABILITY IN ARCTIC AREAS

According to the literature (see e.g. Imrhan, 1992), the proposed guidelines for equipment design for the Arctic conditions that will eliminate or decrease the ergonomic problems are listed below:

i) Visual access: this involves features in design which prevent physical barriers in the line of sight between the part being worked and the eyes.

- Have means for large heavy equipment to be moved easily from one position to another, so that the worker’s line of vision is not blocked.
- Mount the parts or component in a way that the maintenance personnel are not compelled to remove other parts to see the failed component.
- Provide the mechanical aids which can position or reposition the machine in different planes of space and at various heights above the floor, in order to prevent maintenance personnel from adopting an awkward working posture when trying to see their work. This will prevent maintenance personnel from using more energy due to bulky clothing as bulky clothing restricts the movement of personnel and results in forceful body movements in order to perform the task.
- Provide adequate illumination for the task (inside and outside), taking into consideration the limits of human visual capacities. Dealing with small parts or components requires better illuminance levels and better contrast. For inside work the visibility can be enhanced by providing temporal uniformity of lighting. For outdoor the illumination level must be uniform to the surrounding of the worker in order to avoid shadows. In Arctic areas it is usually dark most of the time, therefore a sufficient
amount of lighting should be installed in order to provide complete sight of the work area.

- Provide automatic activation of internal and external lights for safety, where access is in close proximity to danger areas.

**Anthropometric access:** The physical access should accommodate at least 95% of the potential population of the maintenance personnel, and should be designed considering the cold-protective clothing. The following should be taken into consideration:

- Special apparel or bulky clothing, heavy shoes worn by the maintenance personnel.
- Whole body access – for a single person or more than one person.
- Segmental access – relating mostly to the arm or hand with or without hand-tools while using gloves.

**Design features for physical access:** In order to get easy access to the equipment or component some design features are stated below:

- Design and locate the bulkheads, brackets and other units so that they will not interfere with removal or opening of the covers of units.
- Design the equipment in a way that maintenance personnel are not forced to remove non-failed components in order to access the fail component. This can save a significant amount of maintenance downtime.
- Allow sufficient space around the parts considering maintenance personnel wearing winter clothing so that the hand can grasp, remove, manipulate and replace these parts easily.
- The material characteristics of equipment must take into consideration of their characteristics in cold. Therefore, design the equipment by using materials which are less vulnerable in extreme cold.
- Design the equipment with an easy locking system rather than using nut-volt or screw. This can save time and exposure to the cold.

**Task simplification:** The following considerations should be followed for the easy running of the maintenance process:

- Design to promote quick identification of malfunctioning.
- Design to minimize the number and the complexity of maintenance tasks.
- Minimize the number and variety of types of tools and test equipment that are required for maintenance. Avoid frequent tool changes and the use of incorrect tools in order to avoid supply problems.
- Use standardized equipment in order to minimize the number and type of tools needed for maintenance purposes.

The maintenance time or errors can also be reduced by designing out the source of the errors, but the designing out solution may create another hidden problem.

5. **CONCLUDING REMARKS**

In order to improve maintainability and ensure the availability of the system, it is necessary to implement the above recommended guidelines at the early stages of the design phase of equipment. In a study by Seminara and Parsons (1982), it was reported that the maintenance personnel had pointed out limited access or insufficient clearance for maintenance, equipment not designed to facilitate maintenance, and limited mobility for men and equipment. Therefore, the introduction of ergonomics principles in the design stages not only reduces the maintenance downtime but also reduces the exposure to cold, thus preventing maintenance personnel from suffering cold injuries. The limited exposure to cold will enhance the cognitive and physical performance too. In this paper, only design-related issues have been
considered; other issues like characteristics of equipment, metals, and cost, have not been discussed. This paper also provides a basis for future work on how maintainability can be improved by introducing ergonomics principles in the offshore industry installed in the Arctic region.

REFERENCES


