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Occupational safety management in the offshore wind industry – status and challenges

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Abstract

An overview of accidents and potential occupational accidents in the offshore wind industry is shown. There are indications that the number of accidents is relatively high. Based on a model for safe operations, status for as well as challenges for safety management in the offshore wind industry are presented. The paper concludes by presenting topics for further research.

Keywords: safety; offshore wind; occupational safety; safety management

1. Introduction

Safety challenges related to novel technologies and work processes often follow a bathtub-curve. In the beginning of a life cycle, equipment, people and organizational structures often lead to unwanted incidents. The early days of the offshore oil and gas industry at the Norwegian shelf is an example of this. After some time a better and more constant safety performance is established which often increase in later life cycle phases when equipment, people and organizational structures and cultures start to wear out. The deepwater offshore wind industry is a novel industry, which could be experiencing sever safety challenges in its early days. An overview by Tveiten et al. [1] indicates that the frequency of occupational accidents in the offshore wind industry is high and includes accidents with fatal outcomes. Occupational safety must thus be dealt with during all life cycles of an offshore wind farm: design, installation, operation and maintenance, and decommissioning.

This paper first provides an overview of hazards and accident scenarios. Second, the paper discusses safety management requirements to ensure that these and others accidents, hazards and vulnerabilities are

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either avoided or dealt with within the offshore wind industry. Third, the paper identifies needs for further research.

This overview of occupational accident scenarios and the discussions of safety management requirements are mainly based on two sources: a review of current research literature and mass media articles [1] and presentations at the conferences European Offshore Wind Health and Safety Conference 2011 (EOWHSC 2011) and a session on health and safety at the EWEA offshore 2011 conference.

The paper is delimited to studying occupational safety, i.e. related to personnel accident prevention.

Safety management is not distinctively different from other types of management. There is a broad range of different interpretations of what management is as well as many practical ways of performing management. Basically, management can be understood by two concepts; administrating routine tasks and leading/guiding organizational processes [2]. Management can thus be interpreted as the totality of activities conducted in a more or less coordinated way to control something. This 'something' is in this paper occupational safety related to offshore wind farms, i.e. related to personnel accident prevention. Safety management can thus be interpreted as the totality of activities conducted in a more or less coordinated way to control hazards and vulnerabilities in such a way that accidents, failures and disturbances are either avoided or dealt with in a manner that makes systems sustain required operations. Safety management consists of a range of formal and informal different elements, e.g. risk assessment, management of procedures, training, communication, managers' commitment, etc. For an overview of elements, see e.g. Reiman and Oedewald [3]

Safety management cut across different dimensions. It must be conducted at all levels of an organization from top management to the sharp end. In addition, the organization must integrate with stakeholders e.g. authorities, labor organizations and contractual partners [4]. Safety management must be conducted at all phases of a lifecycle [5]. Although safety management has mainly focused on structural topics (goals, hierarchy, rules, procedures) it must also consider other perspectives on management (e.g. human resources; power and decision-making; values and culture [6].

Different contexts require different management approaches. The offshore wind farm industry is in its early days, it is thus natural to focus on the design phase. However it is equally important to think about conceptual solutions for later life cycle phases.

2. Occupational accidents in offshore wind

2.1. Reported offshore wind farm accidents

The publicly available information on accidents and incidents on offshore wind farms is scattered and lacks detail. Tveiten et al. [1] identified two main sources of incident information: the Caithness Windfarm Information Forum (CWIF) database on wind farm incidents, and an American report by Sharples and Sharples [7]. Both these sources provide an overview of different things that has gone wrong on offshore wind farms, including human injuries. Sharples and Sharples [7] state that it seems that neither the industry nor authorities gather information about offshore wind farm incidents. However, Renewable UK does have a reporting system for health and safety incidents for onshore and offshore wind farms, but access to the database is subject to confidentiality agreements between participants and Renewable UK.

Based on the above mentioned sources, a detailed overview of occupational accidents in offshore wind farms, which also include death injuries, is shown in Tveiten et al. [1]. The sources base their information mainly on mass media articles, implying that that the amount of information is limited. Scientifically, the validity of the data could be questioned. Furthermore, it must be assumed that there are dark figures. The overview indicates that the most frequent types of incidents (accidents and near-accidents) are:

- Incidents related to lifting operations and falling objects during the installation of offshore wind farms, including two fatal accidents in the UK.
- Incidents related to operation of jack-up construction vessels. It is reported 14 accidents in the period 1999-2008 [7].
- Accidents related to working in height
- Accidents related to falling or moving objects
- One fatal diving accident happened in 2010 outside Germany.

2.2. Reported safety challenges

There are some reports that partly are mentioning safety challenges. A report by HSE [8] identifies two principal occupational accidents related to offshore wind farms: 1) accidents related to lifting operations and operation of jack-up construction vessels and 2) accidents related to access and egress, working at height, and emergency response related to maintenance and minor repairs. The HSE report has been criticized by Atkinson (2010) for not considering hazards related to electrocutions, diving, underwater hazards and evacuation from tower platforms in the event of fire.

The overview of mass media descriptions of wind farm incidents by Tveiten et al. [1] also shows that severe sea conditions are a safety threat during installation, in particular related to access, egress and evacuation. Different access methods by boat operate at different significant wave heights [1], e.g. 2.5 meters. Numbers provided by the Norwegian Meteorological Institute, shows that the significant wave heights for Ekofisk is lower than 2.5 meters 71% of the time on a yearly basis [1]. Further north, at Gullfaks, the significant wave heights is lower than 2.5 meters 54% of the time [1]. The operation envelope is thus limited based on weather conditions, which again can lead to conflicting objectives of safety and efficiency. Conflicting objectives are a known contributing factor to several accidents in different sectors.

Gerdes et al. [9] made a case study of European offshore wind farms in order to gather and evaluate experiences and lessons learnt from planning and development procedures from eight offshore wind farms. The only potential accident mentioned in the report is ships colliding with wind farm installations.

2.3. Accident scenarios

Tveiten et al. [1] provides an overview of accident scenarios. For the installation and commissioning phase, the following occupational accident scenarios are identified: vessel or drifting installation on collision course; human overboard; capsizing of vessel; anchoring failure, (dynamic) positioning failure; electrocution; falling from height; squeezing; cutting; diving incident; falling object; fire; and helicopter crash. The list above is also relevant for the operation and maintenance phase, however for this phase Tveiten et al. [1] adds the following scenarios that might lead to occupational accidents: structural failures, blade failures; and extreme weather conditions

3. What is required to ensure safety?

The previous section indicates, despite of the scattered data and assumed dark figures, that there is a high frequency of occupational accidents in the offshore wind industry which include fatal injuries. What can be done to avoid or deal with the hazards and scenarios?

So far, there are no indications that main principles, tools and methods in occupational safety management in the offshore wind industry should differ significantly from safety management approaches in other industries. In general, there are several different and complementary approaches to safety available in both practice and research. For example: energy-barrier strategies; experience feedback; risk-based management; resilience engineering; safety culture; fault tolerance; etc.

Schiefloe [10] offers a model for safe operation in an organizational perspective, that includes several of these approaches (see Fig. 1). The model shows five basic sets of organizational abilities for safe operation: reliability; sensitivity; proactive response ability; reactive response ability; and learning from incidents. In the following, each of these characteristics is described and discussed related to safe offshore wind operations. A status for safety management in the offshore wind industry is shown for each ability. The aim of this discussion is not to show a complete picture of occupational safety management in the offshore wind industry, but rather to give indications of the status and possible R&D tasks.

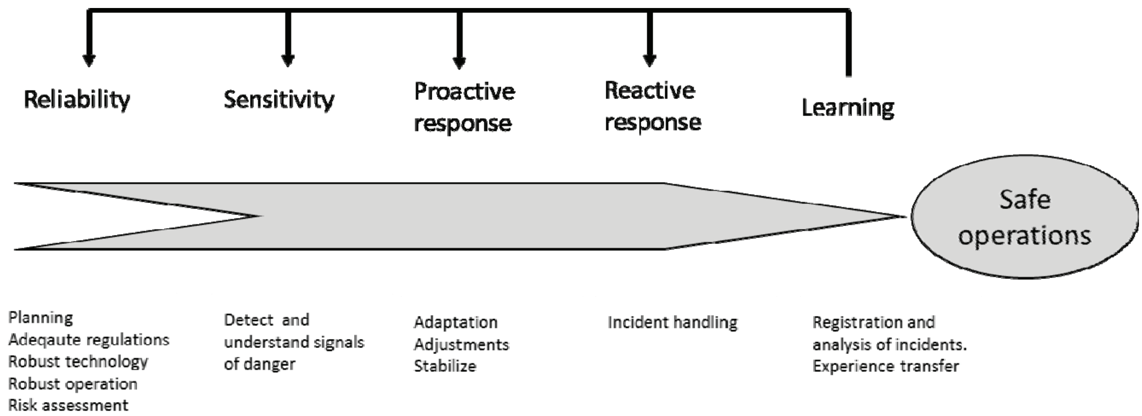

Fig. 1. Organizational preconditions for safe operation, Schiefloe [10]

3.1. Reliability

Reliability is here related to the ability to make plans that ensures safety related to technology, operators and organizational structures. Robust barrier systems and reliability of machinery, equipment etc is of course important here, as this also influences the safety of workers. This type of reliability is not considered here, since this paper is focusing on organizational safety issues. However, in an organizational perspective, reliability is also related to developing and implementing a good organizational structure for safety, e.g. policies, procedures etc. Adequate regulations from authorities are another important prerequisite in providing reliable operations. The organizational ability to be reliable is dependent on risk assessments. Traditionally, design risk assessments have been quantitative assessments. However, also qualitative risk assessments are important for operational planning, e.g. job safety analysis.

Concerning organizational reliability, the status of the offshore wind industry seems to be:

- There is no clear authority responsibility and regulations for offshore wind safety, neither in Norway [1], the UK [11] nor in other countries
- Atkinson [11]. indicate that recognized standards and guidelines for safe operations of offshore wind farms are missing. This is supported by presentations at the EOWHSC2011and EWEA offshore 2011, e.g. Noren [12]. There are however two exceptions. First, there is a European standard EN 50308:2004 "Wind turbines: Protective measures. Requirements of design, operation and maintenance" that focus on safe work conditions for workers, related to e.g. access and egress, ergonomics inside the

installation, lifting operations and climbing facilities. The standard is being updated. Second, RenewableUK have published a best practice guideline for health and safety management at their webpages.
- Training is an important part of preparing the organization to be reliable. There is an initiative from the global wind organization (GWO), consisting of 16 of the main actors in the offshore wind industry, that is working with a common training standards to be released in 2012. The basic training includes: first aid, manual handling, working at heights, fire awareness and offshore sea survival [13]
- For quantitative design risk assessments, there have been concerns related to moderate amount of input data to the assessments [14]. Such an approach to risk assessments is frequency-oriented based on historical data. There are today other approaches to risk assessment available that are not based on frequencies of already occurred events (is the future a repetition of the past?), e.g. Aven [15] and Vatn [16] who are occupied with expressing risk as uncertainty about future outcomes based on available knowledge from different sources.
- There will be different stakeholders involved in different phases of a wind farm life cycle. It is thus required to establish responsibilities and communication routines for safety management in all situations and phases of a wind farm life cycle [17]. As the phases (e.g. installation and operation) may coexist, roles and responsibility need to be clear for these situations as well [18]. In the offshore petroleum industry the responsibility for safety management is placed at the main company in order to avoid conflicts and confusion about safety management responsibilities.
- Change management is an essential part of safety management and risk management. When changes in the preconditions for assessments or plans changes, these changes should be assessed and handled. The offshore wind industry is also changing: e.g. bigger components, taller towers, going further offshore, more powerful turbines, etc. These changes need to be addressed since they could change the preconditions of safety management plans and actions [18].

3.2. Sensitivity

Sensitivity is here related to the ability to detect and interpret signals of danger. Based on Hollnagel [19], this ability broadly consists of two groups. First, an ability to monitor what is going on at current time, second a complementary ability to anticipate future developments, challenges and opportunities. These abilities are related to one of the main principles in safety management: diagnosis (identify symptoms; find causes; treatment; and control) [20]. Risk assessment, which was discussed related to the organizational ability to be reliable, is relevant for the sensitivity reliability as well. For the offshore wind industry the following trends and challenges are relevant:
- Envelopes for installation, operation and maintenance are dependent on the weather conditions. Both monitoring and anticipating wave heights and wind is essential to ensure safety of offshore workers. A particular issue for offshore wind energy is to ensure adequate and updated rules for access and use of vessels with regard to weather conditions [1]. What are the limits for using vessels for access and how is weather and wave height monitored?
- Remote monitoring seems necessary for wind farms far from shore as one wants to limit human presence in particular in bad weather conditions, e.g. use of robots for maintenance monitoring and work etc. Reducing the need for access and improving the access environment will reduce occupational accident risks for offshore workers. The technology needs to be reliable and there must be a high level of trust in order for remote presence to be successful.
- Collisions with vessels involved seem to be one of the most probable incidents in the industries. Eade [21] shows surveillance systems that have been developed and designed in to ensure safety of navigation,

- In other sectors such as the construction industry, job safety analysis (JSA), is a central tool to make sure that involved personnel get an overview of hazards and vulnerabilities related to the job they are about to do. In that sense to process with a JSA is an important contributor to increased risk awareness.

3.3. Proactive response ability

Individuals and groups' abilities to adjust and adapt to known and unknown situations are essential in order to avoid incidents from escalating into damage and loss, either by activating plans and procedures or by adjusting performance to the situation. For some situations it is possible to prescribe expected behavior by rules and procedures. However, it is often required that individual and collective adjustments are made to match current demands and resources to ensure that things go right [19]. Following procedures to the letter can be inefficient or unsafe. To compensate for this incompleteness individual and collective adjustments are made to produce successful outcomes. As a result, there is a need for adaptation to cope with complex, unanticipated, interleaved and conflicting tasks. For such systems, safety management needs to balance and integrate compliance and resilience in a careful manner [22]. Two issues could be relevant to offshore wind related to proactive response ability:

- It is unknown what the status for the offshore wind industry is related to this ability. On a general level, a proactive response ability is dependent on recourses, time, skills and knowledge. Successful recoveries in the oil and gas industry indicate that local knowledge and experienced workers are important prerequisites. Related to this issue it is interesting to note that a concern was raised at the EOWHSC2011 related to the required skills and knowledge of offshore wind worker, who will join the industry with different experiences from different related industries [18].
- Another interesting question is to what degree can operations be planned in advance and to what degree it will be required to adapt to the situation at the work site. The formal safety management system and safety training should be fitted to the answer to the question.

3.4. Reactive response ability

This ability is related to response to an incident after it has occurred, i.e. emergency handling. Emergency handling in the offshore wind energy industry include rescuing personnel, containment of possible environmental pollution and fire fighting. In addition, when few personnel are present during an operation, there is a risk that accidents and incidents are not detected in time and emergency handling become difficult to plan and activate. The following issues are found to be important for emergency operations in offshore wind farms [1]:

- In case of fire, access to areas safe from fire in turbines can be difficult. If personnel are present when a fire starts, there are few alternative escape routes and few safe areas to wait for rescue. It has also been suggested that the tower may act as a chimney and this may make it difficult to open access doors etc. in the lower part of the tower.
- Evacuating a sick or injured person from the nacelle may be challenging as ladders inside and outside the wind turbine tower are steep and may require the use of both hands when climbing. Evacuating persons from wind turbines due to changed weather conditions may also be a challenge.
- Going further offshore implies that the farms could be beyond range of rescue boats. Alternative travel methods or onsite accommodation must be considered. Generally, use of helicopters close to an installation is risky. If helicopters are to be used for rescuing personnel in the sea or stranded at the turbine, the helicopter may not be able to get close enough. Use of a vessel may be the only solution,

and there are currently limits on the conditions in which vessels can be used (depending on wave height etc.).

3.5. Learning from incidents

Another main principle in safety management is feedback control mechanisms, i.e. an experience-based approach to safety management. The report by Tveiten et al. [1] as well as presentations at the EOWHSC11 show that accidents occur in the industry [14;23;24]. Accidents and near-accidents are not wanted, however when they occur they represent an opportunity to learn and improve:

- It seems that neither the industry nor authorities gather information about offshore wind farm incidents [7], one exception is RenewableUK (the trade and professional body for the UK wind and marine renewables industries) who have established a reporting system. On the other hand Streatfeild [25] claims that there is a industry problem related to lessons learned schemes incident sharing & communication issues
- Establishment of recognized industry safety performance indicators is missing [1]. Both leading and lagging indicators and systems for data collection need to be established, which is also relevant for reliability data.
- Offshore wind is not the first industry that experiences safety challenges in marine activates. Experience transfer from other relevant industries such as offshore oil and gas, marine operations and fish farming as well as onshore wind could improve offshore wind safety management
- Information about failures as well as successes needs to be shared among actors in the industry. Safety is not a trade secret; openness should be promoted to strengthen safety work for all actors in the industry.

4. Conclusions and further research

Parts of this paper are based on a non-scientific material. The validity of the paper can thus be questioned. There is a lack of scientific attempts to study implications for occupational safety as well as what is required to ensure safety in the offshore wind industry, which is partly explained by the novelty of the industry. Nevertheless, the paper gives some indications of accidents and potential accidents in the industry as well as an indication of the status of abilities to ensure safe operation in the industry.

Both safety and offshore wind need to be addressed in a life-cycle perspective: design, installation, operation and maintenance, and decommissioning. At current time, most of the efforts are focused on the design phase (i.e. establishing organizational reliability, ref. figure 1). This is important work, since the safety barriers, plans and training courses established in this phase influences safety performance in later life cycle phases.

Based on the elaboration of safety management in this paper, the following topics for further R&D activities can be suggested:

- Experience transfer from other industries: offshore oil and gas; onshore wind; marine operations; fish farming. What are the success and failures in managing safety in these industries, and how does these relate to offshore wind? What is the relevance of these industries to offshore wind?
- Development of risk assessment methods that are not dependent on historical incident frequency data
- Development and implementation of an industry system for incident reporting and establishment of safety performance indicators.
- Establish arenas for learning across organizations. Such learning should emphasize to study both failures as well as success (narratives, best practices).

- Development of international standards/guidelines for occupational safety management in the offshore wind industry that ensures holistic safety management in a life cycle perspective
- Identify regulatory requirements and type of regulation
- Identify success criteria for contractor involvement in safety planning and practice

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References

[1] Tveiten C, Albrechtsen E, Heggset J, Hoffman M, Jersin E, Leira B, Norddal, PK. *HSE challenges related to offshore renewable energy. A study of HSE issues related to current and future offshore wind power concepts* SINTEF report No. A18107

[2] Levin M, Klev R. *Forandring som praksis : læring og utvikling i organisasjoner.* In Norwegian [Changes in practice: learning and development in organizations] Bergen, Norway: Fagbokforlaget; 2002.

[3] Reiman T, Oedewald P. *Evaluating safety-critical organizations – emphasis on the nuclear industry*. Swedish Radiation Safety Authority report number 2009:12

[4] Rasmussen J. Risk Management in a Dynamic Society. *Safety Science* 1997; **27**(2/3);183-213.

[5] Hale A, Heming BHJ, Carthey J, Kirwan B. Modelling of safety management systems. *Safety Science*, 1997; **26**(1/2); 121-140

[6] Hale A, Hovden J. Management and culture: the third age of safety. A review of approaches to organizational aspects of safety, health and environment. In Feyer & Williamson (Eds.), *Occupational Injury: Risk, Prevention and Intervention*. London: Taylor & Francis; 1998

[7] Sharples M, Sharples BJM. *Damage and Critical Analysis of Accidents to Assist in Avoiding Accidents on Offshore Wind Farms on the OCS*. Report prepared for Minerals Management Service, Department of the Interior, US. Project No. 633, Contract M09PC00015; 2010

[8] HSE (Health and Safety Excecutive) *The health and safety risks and regulatory strategy related to energy developments*. An expert report by the Health and Safety Executive contributing to the Government's Energy Review; 2006.

[9] Gerdes G, Tiedemannm A, Zeelenberg S. (2006). *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms*; POWER report 2006

[10] Schiefloe, PM. Personal communication. 2011

[11] Atkinson P.Securing the safety of offshore wind workers. *Renewable Energy Focus*. 2010;**3**:34-36

[12] Norén, C. Risk based health and safety system for offshore wind farms, Lessons Learned. Presentation at *EWEA Offshore 2011 conference;* 30 November 2011

[13] Rose, C. Universal HSE procedures: Avoiding excessive regulation and shaping efficient standards. Presentation at *European Offshore Wind Health and Safety Conference* 1-2 June 2011

[14] Hansen, A.M. Safety Management in offshore wind. Presentation at *European Offshore Wind Health and Safety Conference* 1-2 June 2011

[15] Aven, T. *Foundations of risk analysis.*Chichester: John Wiley; 2003

[16] Vatn J. Can we understand complex systems in terms of risk analysis? *Journal of Risk and Reliability*. In press

[17] Fischer, G. Safety management in offshore wind farm projects. Presentation at *EWEA Offshore 2011 conference*; 30 November 2011

[18] Finn, P. Offshore Wind HSE Trends. Presentation at *European Offshore Wind Health and Safety Conference* 1-2 June 2011

[19] Hollnagel E. The four cornerstones of resilience engineering. In C. P. Nemeth, E. Hollnagel & S. Dekker (Eds.), *Resilience engineering perspectives; Preparation and restoration.* Ashgate: Aldershot; 2009

[20] Kjellen, U. *Prevention of accident through experience feedback.* London: Taylor and Francis; 2000

[21] Eade, P. Marine Coordination – Maritime Safety and Health & Safety. Presentation at *EWEA Offshore 2011 conference;* 30 November 2011

[22] Grøtan TO, Størseth F Integrated Safety Management based on Organizational Resilience. Paper presented at *ESREL* 2011

[23] Herd, T. Understanding the issues surrounding personnel liability during the initial development and construction phase. Presentation at *European Offshore Wind Health and Safety Conference* 1-2 June 2011

[24] Butler, P. Offshore Construction and Personnel HSE. Presentation at *European Offshore Wind Health and Safety Conference* 1-2 June 2011

[25] Streatfeild, C. Defining a suitable health & safety competence framework – A view from the UK. Presentation at *European Offshore Wind Health and Safety Conference* 1-2 June 2011