Knowledge Management: A Cross Sectorial Comparison of Wind Generation and Naval Engineering

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Abstract. Offshore wind farms and naval vessels are examples of complex systems. A number of differences exist, e.g. the first is an exemplar of a developing technology, the second a technology having been developed and enhanced over centuries. Never the less a number of similarities exist, e.g. the development of responsive systems in physically demanding environments. Each of the technologies adheres to a prescribed product lifecycle, e.g. "ISO 15288, Systems and software engineering -- System life cycle processes", whereby each phase has distinct information and knowledge requirements. Furthermore, the adoption of a structured lifecycle ensures each technology considers the complete lifecycle and its integration within a potential system of systems. This cross sectoral study will review in-service knowledge management in two different fields of engineering, firstly Offshore Wind Generation which is a complex infrastructure system and secondly Royal Navy vessels which are complex marine engineering systems.

Keywords: Knowledge Management, Offshore Wind Farm, Naval.

1 Introduction

This paper details a comparison of Knowledge Management (KM) in two distinct engineering domains, i.e. offshore Wind Farms (WF) and marine engineering in the Royal Navy (RN). Each domain may be viewed as a system of systems, i.e. whose system elements are themselves systems; typically these entail large scale inter-disciplinary problems with multiple, heterogeneous, distributed systems [1]. The KM issues are particular to each technology, however, a number of similarities and differences are seen to exist. The approach taken is as follows. After outlining key characteristics KM the paper examines each domain and summarises and compares a number of issues during in-service.

2 Knowledge Management

The Knowledge is a relatively simple word; indeed the Oxford English Dictionary defines knowledge as "awareness or familiarity gained by experience" [2]. Within an enterprise, knowledge may be seen as the cumulative data/information acquired and developed, both tacit, written and recorded. The function of preventing its loss/corruption and thus obviating the time, experience and effort required to recreate may be seen as Information Management (IM). KM encompasses IM but also extends the capability and value of information by providing a Knowledge Lifecycle [3].

Charles Dickens in "A Tale of Two Cities" declares, "It was the best of times, it was the worst of times" [4]; KM may be viewed similarly. The "best of times" is reflected in the capability of hardware and software technology, whereas, "the worst of times" is illustrated by the lack of structure, accessibility, volume, etc. and potential unknown value of a strategic resource.

According to Wong et al. [5], there are four key activities in KM – creation, mapping, retrieval and reuse of knowledge. Other authors such as Goh and McMahon [6] may describe these activities as a process of knowledge capture (collection), feedback and reuse. With respect to the challenges in KM, there is not a very clear boundary which distinguishes the challenges faced in each activity of KM. However, with the advancement in information technology, one can easily know what the challenges are and where they lie. For instance, McMahon and Ball [7] stated:

> "We are constrained now not by the ability to capture but by our ability to retain, organise and interpret the information (and to some extent by our ability not to be overwhelmed by the quantity of data that we can capture)".

This implies that with the amount of data we can capture now, much effort is also needed to ensure knowledge feedback and reuse, suggesting that data has no value if it is not used for a purpose [8]. Furthermore, information reuse only occurs when it has been assimilated and used in new applications, producing useful insights and knowledge [6], for example – using in-service knowledge for new product development.

3 Offshore Wind Power

The gradual shift in trend from onshore to offshore wind power, which has largely been due to social and political reasons [9], has resulted in the steady growth of the offshore wind sector. However, the offshore wind sector is still in its nascent state, hence lots of new ideas and concepts needed to cope with the hostile marine environment keep emerging [9]. Examples of such new concepts can be seen in the evolution of offshore wind turbine foundation structures [10] and the pre-assembly of parts of the turbine on floating vessels while ashore before shipping to the offshore environment to install.

Offshore WFs are complex engineering systems which harness the energy from wind to generate electrical power. The nature of this complexity is not only defined by the number and interactions of systems that comprise the WF, e.g. electromechanical, structural, control, etc. It is also defined by the considerable number of inputs from nearly every field of engineering and many of the natural and even social sciences [11]. The WF itself is made up of individual wind turbines which are all interconnected to the grid. Furthermore, the extended supply chain related to the transportation, installation and operations & maintenance of WFs [11], which are heavily influenced by the weather and sea conditions [9,12], also contribute to the complexities of offshore wind power life cycle management. Other complexities result from the broad mix of stakeholders involved throughout the life cycle of offshore wind. Of interest in this paper are the issues relating to knowledge and information management during the in-service stage, which arise as a result of these complexities.

4 Naval Engineering

Unlike offshore wind power the RN has existed since the reign of King Henry VIII (1491 ~ 1547) and his development of a "Navy Royal". The design and configuration of a naval vessel is intended to provide a "sustained" capability as described in the Concept of Operations, e.g. air defence, humanitarian relief.

Capability requirements may be conflicting and competing, e.g. stable and maneuverable platform, capable of operating from the arctic to the tropics, fuel efficient but able to sustain 30+ knots, deck space for weapons and sensors but clear for replenishment at sea, etc. KM is utilised at the earliest stages of the lifecycle, whereby previous experience and designs are included / excluded. Indeed a modern naval vessel will encompass more than 100 integrated hard systems [13], linked electrical, hydraulically, mechanically, etc. Furthermore, the complexity of modern naval vessels dramatically skews the comparative cost of systems and hull,

> In the United Kingdom, systems represent the biggest percentage of the price of a warship – 70% compared to 30% for the hull. This is in stark contrast to commercial vessels, where almost the reverse is true, i.e. 20% systems, 80% hull [14].

Preventive maintenance is undertaken to sustain the capability of the vessel: the RN utilise Reliability Centred Maintenance (RCM). The methodology was selected following a review of failures in a Type 23 Frigate and comparing them with the Age-Reliability Patterns developed by Nowlan and Heap [15]. The results indicated within the naval domain only 7% of failures may be attributed to "wear" (Pattern A to C) whilst 93% were "random" (Pattern D to F) (Figure 1). It should be noted KM is incorporated at the early stages of formulating the maintenance package to ensure "lessons learnt" are incorporated.

Similar to offshore wind power, a broad mix of stakeholders are involved throughout the life cycle of a naval vessel, e.g. RN, Ministry of Defence (MOD), Babcock, BAe. Issues related to KM during the in-service stage will be reviewed.

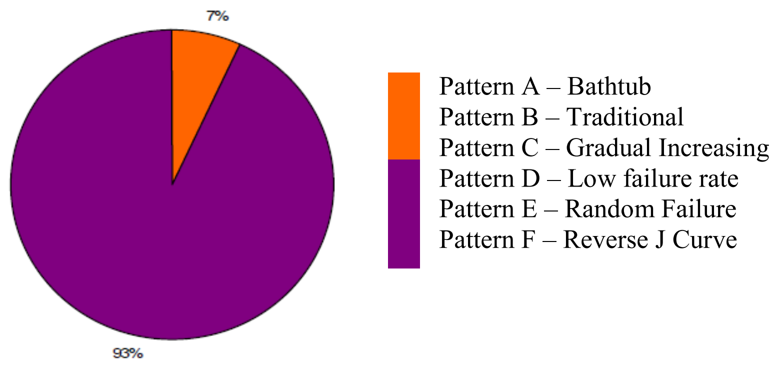

Figure 1: Distribution of failures – Type 23 Frigate [16]

5 Current State-Of-The-Art in Knowledge Management and Challenges

Ford et al. [17] previously identified that the major challenges the wind industry face in life cycle KM are observed during the in-service stage. However, to build upon this and expand further, a brief review of the state-of-the-art of in-service KM in the offshore wind sector would be done. This would provide some context to the issues and challenges during in-service KM specific to offshore WFs.

Previous authors would agree that majority of the challenges experienced during the in-service stage of offshore wind turbines arise as a result of the harshness and unpredictability of the offshore environment. Furthermore, typical offshore WFs are sited at remote locations at distances from the shore ranging from about 5km to more than 50km [10]. Hence, be it transportation and logistics, or operations and maintenance, weather effects are a major source of uncertainty whilst in-service. This has prompted the need for extensive forecasting, planning and scheduling of tasks and activities, in a flexible manner so as to avoid delays caused by weather and sea conditions. Specific to KM, due to the remoteness of offshore WF's, the industry's state-of-the-art are remote monitoring and control through condition monitoring systems (CMS) and supervisory control and data acquisition (SCADA) systems. SCADA systems were primarily installed in wind turbines to measure operational and environmental conditions, such as wind speed, ambient temperature and temperature/pressure sub-systems in the turbine [18]. On the other hand, CMS are used to monitor parameters such as vibrations, acoustic emissions, and oil particle counts, to name a few. These two remote monitoring techniques produce large quantities of data collected either as 10 minute averages or even every 10 seconds. Apart from the remote monitoring data acquisition systems, other manual or human assisted techniques exist for documenting in-service records. These include: service or work orders, inspection reports and maintenance, repair and overhaul reports. Unlike the automated remote CMS and SCADA techniques, knowledge captured through these means are only obtained on an interval basis, depending on how frequent such service or maintenance actions are required.

1.) KM Challenges in Remote Monitoring Techniques:

One of the main issues with remote monitoring is linked to the size of data generated. Having huge data collected from a large number of turbines poses challenges in analysing and interpreting the data. Fast growing databases from remote monitoring of offshore WF's require advanced signal processing techniques and data mining to extract the most useful information [19]. However, such data are not without noise and can result in generating poor models [20]. It is also difficult to convincingly interpret and convey the results of analysis obtained from remote monitoring to wind farm managers and specialists [20].

Finally, there are concerns about the reliability and accuracy of the sensors that acquire the data [18], for instance, if the sensors are not installed properly and in the right location, the data collected might be erroneous. Hence a lot of effort is needed in the design and development stage in specifying remote monitoring technologies and their installation and operation.

2.) KM Challenges in Manual Techniques:

The primary challenge with capturing manual data is the issue with physical access to the WFs. Harsh weather conditions make it almost impossible to even attempt to capture maintenance records from inspections and other maintenance tasks in the turbine. For example, WFs which are just a few kilometers offshore have been previously known to have experienced months with over 20 unworkable days.

When service personnel eventual have access to the turbines there is then the inability to complete maintenance records within the turbine due to safety concerns and space limitations [17]. Hence, technicians who keep record of maintenance activities and inspections may have to result to other means like taking photographs and then completing the reports after leaving the turbine. The time lag between when the inspection is done to when reports are produced depends on the technician and is difficult to control. There is also the possibility of data being diluted and of poor quality between the time the maintenance task is done and when the report is made, since the technician may forget a few details even in the presence of pictures.

Furthermore, since the periods of access to the turbine is largely dependent on the weather and hence not predetermined, there is a risk of inconsistency in the periods between data capture. Hence the accuracy of captured maintenance data heavily depends on the selection of a suitable observation window [9]. For example, maintenance visits should be planned and periodic, giving consistency to findings, i.e. monthly, quarterly, yearly or a period defined by the age or condition of the turbine. However, this is very difficult to achieve for offshore WFs, hence giving difficulty in collating records to make suitable judgments about the service history of the turbines. As maintenance reports are largely a mix of hand written or typed spread sheets, there is always the risk of typographical and spelling errors [9].

A naval vessel will encounter similar issues with respect to the harshness and unpredictability of the marine environment; however, unlike a static WF a vessel whilst in transit may experience large variations in temperature, humidity and movement, i.e. heave, sway and surge in addition to shock and vibration. Unlike a WF, RN vessels have onboard operators and maintainers, however, base support, spares and tools may be thousands of km away [21] or not available due to operational constraints. For example, a Vanguard class submarine will remain submerged for 3 months with no contact or support but none-the-less required to provide 100% availability and capability throughout each patrol.

The RCM process formulates a maintenance regime which enables a maintainer to perform maintenance and ascertain the material state. Data created and utilised by maintainers includes, engineering logs, vibration data, oil samples, running hours, etc. The onboard operational maintenance data is typically objective and structured, e.g. diesel engine hours run. However, if a vessel encounters a defect that impacts the operational capability, assessment by naval command will often necessitate a subjective assessment of potentially unstructured and aggregated data.

6 Summary

It seems that offshore WF's largely rely on remote monitoring for obtaining information about the operational and performance data. Remote access provides the possibility of controlling wind turbines in multiple WFs from a central remote location. Another advantage not immediately apparent is the ability to optimise power production from the wind farm by matching operating and environmental conditions with wind turbine controls. One example of this, is the pitch control [10,18,22] of each individual blades to adapting blade angle to wind conditions so as to provide the optimum power output and noise levels. Even though state-of-the-art remote monitoring techniques are capable of providing useful measures of the condition of the major systems that constitute the WF, WF operators and technical specialists still rely on the information that are collected manually through human effort. The visual inspections, images and measurements taken manually, provide more explicit details about the nature of wear and tear in the turbines.

Given that WF operators need to rely on both sources of knowledge for life cycle management, it will also be useful to identify some common issues affecting both techniques. Some of the general issues with KM in offshore wind include:

- Inconsistency in data file formats: A typical modern WF would have at least a combination of 10-Minute average SCADA data, fault/alarm logs, service orders and O&M contractor reports [23]. Service and O&M reports, unlike SCADA, are a mixture of spreadsheets and hand written reports. As a consequence, a lot of effort is needed in filtering and preprocessing these disparate sources in order to aggregate them for suitable analysis. This poses a challenge of data reuse when seeking to combine data from multiple sources in order to make inferential judgments from it. It also increases the lead time to decision making as more time and effort is consumed in harmonising the information contained in different data sources. Experience by previous research have shown that a substantial effort is needed to connect these different sources [23].
- Organisational (institutional) barriers exist with respect to ownership of failure data of the wind turbine components. For example during the warranty period operators have general information of the number of failures and the general types, but may not have information of their root causes [24].

- Missing or incomplete information is very likely to occur in maintenance records, due to the weather and location effects interrupting scheduled service or inspections.

In-Service KM in the naval domain may be considered to exist in two distinct spheres, i.e. onboard and onshore. The onboard data and knowledge may be considered "tactical", i.e. single vessel, local, immediate, single stakeholder, whereas onshore has a "strategic" focus, i.e. aggregation of multiple vessels / systems, remote, latent, long term planning, multiple stakeholders. The "Common knowledge" relates to the interface and interaction of onboard and onshore knowledge

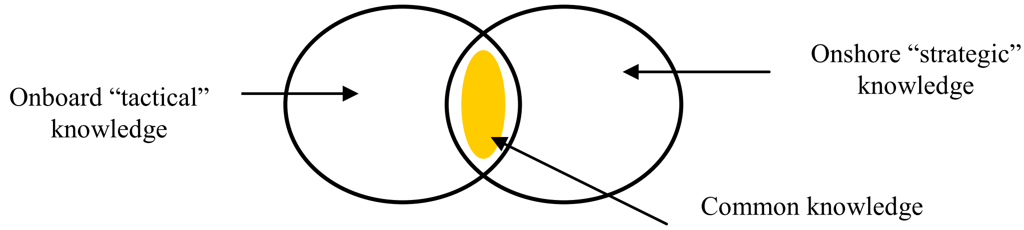

Figure 2: Onboard/onshore knowledge spheres

The onboard management, maintenance information flow and KM is extremely hierarchical, e.g. junior operator/maintainer → senior maintainer → junior officer → Marine Engineering Officer (MEO). The MEO and staff have an enduring responsibility for "the good material order and maximum availability of all equipment and systems within its responsibility, in order to maintain the seagoing and fighting capability of the ship" [25]. Objective information originates from discrete systems and is collected by junior operators/maintainers which is collated, processed, aggregated and analysed by senior staff often requiring a subjective assessment of numerous information sources and influences both internal and external. The combination of structured / unstructured and objective / subjective information may be seen to exist as a matrix (Table 1), i.e.

Table 1: Information matrix

	Objective	**Subjective**
Unstructured	*Sector 1*	*Sector 2* Complex / complicated
Structured	*Sector 3* Simple, e.g. hours run	*Sector 4*

As information passes up the management hierarchy, e.g. typically originating in Sector 3, a broader perspective and higher level of KM function may be seen to exist as it passes to Sector 2. Whereupon the MEO may be expected to fuse numerous information sources / controls / enablers, deliberate and decide upon a course of action. Onboard, a large number of knowledge sources exist, e.g. Standard Operating Procedures (SOP), Books of Reference (BR), work books, tacit knowledge.

Reflecting upon the principles of KM detailed by Wong *et al* [5], the onboard KM process is established, controlled and structured.

The onshore KM and associated stakeholder activity is dependant upon the function / role of the vessel, e.g. Upkeep (deep maintenance), Tasking (operational deployment). The KM activity of assessing the material state of a Tasking vessel and hence its operational capability is primarily the monitoring of Operational Defects, i.e. defects that may degrade the capability of the vessel – as contained within the "Common knowledge". The KM assessment is highly subjective and is frequently dependant upon the tacit knowledge of RN personnel within the context of the mission. The onshore KM of a Tasking vessel may be seen to exist extensively in Sector 2.

Prior to Upkeep, stakeholders responsible for deep maintenance will be dependant upon information that is highly subjective, e.g. diesel generator #1 is a bit noisy. However, a key KM function during Upkeep is the generation of detailed objective and structured information (Sector 3), e.g. survey reports, defects. The formulation of such information facilitates logical decision making, e.g. if valve leaking then replace. It also enables searching and comparison with previous records to enable reuse of existing knowledge.

Onshore, an even greater knowledge bases exists, e.g. design documentation, test spec's, original equipment manufacturer, SOP's, BR's, work books, tacit knowledge. Once more, reflecting upon the principles of KM detailed by Wong *et al* [5], the onshore KM process is also established, controlled and structured.

7 Conclusion

The KM process within the naval engineering domain is "mature", having been developed and refined over considerable time, whereas wind generation has yet to refine its procedures. The issues identified by wind generation, i.e. (i) inconsistency in data file formats and (ii) missing or incomplete information, also exist in the naval domain. However, they are not as prevalent as there is a single customer, i.e. MOD, instead of multiple. Furthermore, the issue of "organisational (institutional) barriers" is markedly less given the support of surface ships is undertaken by a Surface Ship Support Alliance. Consequently, all members of the alliance work together in support of the RN rather than in competition. Finally, the maturity of the naval engineering process and artefact is a key factor in minimising the issues compared with wind generation.

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