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The Fourth International Conference on Through-life Engineering Services

## An Examination of Significant Issues in Naval Maintenance

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### Abstract

This paper summarises qualitative research undertaken within the “In-Service” stage of the lifecycle of Royal Navy surface ships and submarines. Whilst In-Service, Royal Navy vessels will typically cycle through three phases, i.e. Tasking, Upkeep and Regeneration. A series of semi-structured recorded interviews conducted with key stakeholders in each phase identifies and highlights common issues encountered whilst In-Service. Having identified common issues, e.g. risk, obsolescence, manpower availability, etc. additional interviews were undertaken to triangulate the results with other safety critical companies operating and maintaining complex systems, i.e. a power company operating an advanced gas-cooled nuclear reactor, rail infrastructure and Europe’s largest regional airline.

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*Keywords:* Naval; Maintenance; Systems Engineering

### 1. Introduction

This paper reports the outcome of semi-structured recorded interviews with key stakeholders with a view to learning how the stakeholders use information systems to judge the material state of vessels.

The Royal Navy (RN) operates and maintains a fleet of nuclear submarines, surface ships and auxiliary vessels; each may be considered to be an integrated complex system of systems [1]. The vessels vary in size and complexity from Vanguard class strategic ballistic missile nuclear submarines providing the United Kingdom’s (UK) “Continuous At Sea Deterrent” (CASD) to HMS Gleaner - providing advanced surveying capabilities.

Regardless of size and role, “is the ship a safe environment to live on and work on” is a key objective in RN operations [2]. Furthermore, each vessel must be operating safely and safe to operate [3], even when in highly dynamic and potentially threatening environments ranging from the provision of humanitarian and medical relief in Sierra Leone [4] to being subject to possible hostile threats, such as probed by UAVs [5] or surface vessels [6] or an unknown submarine [7].

Unfortunately, naval vessels are “unreliable in the sense that they deteriorate with age and / or usage and ultimately fail” [8], consequently vessels require constant preventive and corrective maintenance.

Vessels are designed for a specific Concept of Operations (CONOPS), e.g. anti-submarine, air-defence, mine counter measures. Changes in maritime doctrine, technology, tactical and strategic threat may render the original CONOPS invalid; necessitating a review of the CONOPS and a change in modus operandi and / or systems.

Interviews were also conducted with other safety critical companies operating and maintaining complex systems to determine similarities and differences. Companies were selected on the basis of operation / maintenance of similar technology, longevity and complexity of the artefact.

### 2. Ministry of Defence Lifecycle

The Ministry of Defence (MoD) utilise the Acquisitions Operating Framework [9] known as CADMID. The acronym refers to six discrete stages, i.e. Concept, Assessment, Demonstration, Manufacture, In-Service and Disposal. The

framework is similar to ISO-15288, i.e. Systems Engineering - System Life Cycle Processes [10].

Within the naval domain, In-Service constitutes the longest stage and is where the largest costs are incurred, in some cases up to 70% of the total cost of ownership of a vessel is expended at this stage [11]. Whilst In-Service a vessel will typically cycle through 3 phases, (i) Tasking –operational tasking in support of UK maritime doctrine (ii) Upkeep – maintenance and upgrade of “hard” systems which may include a docking (iii) Regeneration – testing and reactivation of “hard” and “soft” systems.

### 3. Research Method

Semi-structured recorded interviews were undertaken with key stakeholders in each cyclical phase with a view to learning how the stakeholders create / use information to assess the material state of vessels. Additional “triangulation” interviews were conducted with stakeholders from other safety critical organisations to assess the potential uniqueness of the naval domain. A nuclear power station was selected given the similarity in the engineering domain. A regional airline was selected to assess similarities in operating first level critical systems. A rail infrastructure company was selected given the longevity of the artefact and the high level of availability required in a safety critical environment.

The construct for the interviews was based upon IDEF0; the “function” being, “the assessment of the material state” as a result of Inputs, Controls, Mechanisms and Outputs. This paper provides an overview of a number of the issues that influence the process of assessing the material state. Each recorded interview was subsequently transcribed verbatim and systematically analysed to determine commonality with respect to issues.

### 4. Key Issues Identified

Analysis of the recorded interviews identified a broad range of issues that encompass Controls and Mechanisms associated with material state assessment; these include Risk, Materiel, Suitably Qualified and Experienced Personnel, Vibration Monitoring, Configuration Management. However, this paper will only examine the first three.

#### 4.1. Risk

Risk was often explicitly and implicitly identified by interviewees as an issue. ISO 31000 [12] provides a nonspecific definition of risk that reflects the highly diverse role of RN vessels, i.e., the “effect of uncertainty on objectives”. The taxonomy of risk often refers to the consequence of failure, however, the ISO definition allows for both positive and / or negative uncertainty and does not define the consequence but rather an objective which reflects the naval domain. A naval vessel may be required to fulfil multiple and diverse “objectives”, in a single operational deployment with varying levels of uncertainty and hence risk.

The risk to a vessel and the operational objective is managed by means of duty holders. The RN utilise a

triumvirate of duty holders to discharge a duty of care and manage risk, i.e. Commanding Officer Duty Holder (CODH), Operating Duty Holder (ODH) and Platform Duty Holder (PDH). The role and responsibility of the duty holders was referred to by many of the stakeholders, for example:

*“As the platform duty holder all you want to know that you’ve repaired my rudder stop, so the rudder stop is completely repaired”* [13]

Within the Tasking / Regeneration phase the greatest risk was perceived to be a failure to provide / maintain Operational Capability (OC) which is defined as the measurement of the ability of a platform to perform operational tasks.

*“CO Comment: This defect is a risk to my sustainability and requires swift support to rectify to avoid a potentially significant impact to contingent operations”* [14]

The raison d'être of a naval vessel is the delivery of OC in support of UK Maritime Doctrine, i.e., “The ability to project power at sea and from the sea to influence the behaviour of people or the course of events” [15]. The role of naval engineers is to provide and sustain OC by the application of maintenance, repair of equipments and the restoration of systems following damage [16]. Acceptable risk in a defence / naval environment is highly dynamic and defined by the overall command aim, which subsequently bounds the level of risk considered acceptable, i.e.

*“if you’re just doing a transit or a visit, ... then you would accept far lower risks, if you’re doing a mission of some importance then criteria have moved”* [17]

The variation of risk is exemplified by a safety override fitted on nuclear powered submarines. Since the loss of the USS Thresher, a “battle-short” mechanism has been provided in submarines to override the automatic reactor shutdown if an operational emergency demands that reactor power be maintained [18, 19]. Conversely, civilian air and rail operations are extremely risk averse,

*“that’s the biggest thing that aviation doesn’t like, risk. We spend a huge amount of time avoiding risk”* [20]

*“We are very risk averse as an industry... we are constantly trying to operate within the constraints of what we know is the least risky thing to do”* [21]

Naval engineers frequently apply their engineering judgement, i.e. “situations for which there is no formal guidance or policy and will be called upon to use engineering judgement to risk manage events” [16]. A common issue necessitating the application of engineering judgement is compounded risk, i.e., risk on top of risk,

*“that’s where engineering judgement comes into it; it’s almost like having a feel for how many small defects are going to add up to a big defect”* [3]

The comment detailed above was made on a surface ship, however, the issues are equally valid within the submarine domain.

*“As defects emerge, as issues occur we’ll review them and then we’ll have to make a judgement whether that will affect our ability to sail or operate correctly”* [17]

Delivering and sustaining OC may not necessitate the availability of weapons or sensors, but potentially more benign systems, e.g. davit’s or winches.

*“AAV’s [Alongside Assurance Visit] thwarted in afternoon due to faulty boat davits.” [22]*

Given the physical constraints and operational environment of RN vessels, maintenance operations pose potential risks to maintainers [23, 24].

*“HMS Endurance suffered a major flood in her Engine Room, resulting in the near loss of the ship. At the time of the incident ship’s staff were cleaning a high level sea water inlet strainer... hull valves opened unexpectedly, allowing water into the ship... the panel believes the potential for complacency to establish itself was high” [25]*

The majority of RN vessels are relatively “old” platforms, the average age being, Type 23 frigates 19 years, Trafalgar class submarines 25 years. The incidence of maintenance errors increases due to the increase in maintenance frequency as the equipment becomes older [26]; this is also relevant within a naval domain given the turnover of maintainers.

*“we came back with a defect ... our hydraulic systems, all three different separate systems by the end of it had been cross connected and re-linked, so like we had one system doing everything” [27]*

Maintaining OC was the absolute criterion in the scenario detailed above; however, risks may include time pressure, as well as defects in work planning and safety management [28]. A lack of experience in maintaining complex systems can produce unintended consequences. In the case of a submarine the environment may also be hermetically sealed,

*“The sewage pump broke, we got to empty the tanks regularly, so we worked out we could use HP [High Pressure] air to blow them. Except the guy got the line-up wrong and he blew the ---- in the boat rather than out” [27].*

The requirement to remain “on patrol” and submerged and “empty the tanks” compounded the problem of a failed sewage pump. The management and consequence of compounded risk is managed by the Heads of Department in consultation with the Captain,

*“...the Heads of Department and they will discuss what they think the overall impact is on operational capability and safety and then they will present their recommendations for the Captain” [17]*

Haddon-Cave in his Nimrod Report [29] highlighted the consequence of cumulative risk. Similarities exist with respect to cumulative risk and the role of the CODH in managing a complex system of systems constrained by multiple and potentially conflicting Operational Defects (OpDef) whilst endeavouring to maintain OC.

*“there’s no easy system to combine the individual deficiencies, have you got the required number of pumps or not is easy; but then, when you’ve got that and also something else and something else and that system, what is the overall impact, it can only really be subjective I think” [17].*

Defects that constitute a constraint to OC are articulated to command by means of an OpDef signal. Each OpDef is assigned a category (Table 3) combining “Effect Category” (A ~ Major capability inoperative, B ~ Major capability significantly degraded, C ~ All other OpDef’s) and “Repair Indicator” (1 ~ Immediate rectification, 2 ~ Rectification

required as soon as possible, 3 ~ Rectification not required until next programmed base port period, 4 ~ Rectification may await next programmed Upkeep period)

Table 3. Examples of OpDef Categories & Associated Impact upon OC

OpDef Category (Effect Category    Repair Indicator)	Impact upon OC
A1	1 of 2 Davits OOA [Out Of Action] unable to carry out boarding Ops. Unable to carry out concurrent flying and boat Ops
C4	No redundancy for operating ships pre-wet system

Pre-Wet: System that sprays water over the hull and superstructure to increase survivability from radiological, chemical or biological attack.

The OpDef category indicates the urgency and subsequent prioritisation of support. The category and ensuing management of the risk may be redefined by Navy command. The immediate consequence is a differential experienced by onboard engineers between the anticipated and actual level of support and a potential delay in repair provision.

The risk of complacency is an issue; technicians become familiar with regularly performed tasks that may lead to familiarisation with the dangers, which in turn leads to complacency [30].

*“They de-risk evolutions in their minds, they don’t understand how much peril they’re in, you’re in a metal tube under the water, people forget that” [27]*

A comparatively low number of assets compels maintenance organisations to carefully manage the upkeep work package, endeavouring to complete Upkeep as agreed and available for operational tasking.

*“The problem we’ve got here is that the ship’s programmes now are so ‘bar taut’ that there is no scope for anything to go wrong” [31]*

Maintenance organisations are reviewing their procedures to de-risk and minimise the volume of growth as a result of emergent work / variation orders within an Upkeep project. Regrettably, the onboard maintenance data may not indicate the ‘material state of systems’, resulting in emergent work and increasing the risk to a timely completion of the project.

*“chilled water plants and one of them came in full of mud. Nothing in UMMS [Unit Maintenance Management System] ... there’s no way it was working, yet UMMS never told us anything. ... Fuel, was ‘perfectly fine’ when she came in, yet when I did a fuel flush, I got black treacle out of it and I took 120 metres of pipe work out of the ship, dipped it through the factory, cleaned it, put it back in again 3 week delay to diesels. I’m not joking, treacle, it was treacle and that’s after 3 days of flushing.” [32]*

In order to de-risk the maintenance activity it may necessitate a change in the business process, for example, subcontracting the Original Equipment Manufacturer (OEM) to survey the vessel whilst deployed to determine the material state of the system and undertake the maintenance,

*“we went OEM, cost us a few quid sending them out to ... but actually, it’s de-risk downstream big time ... the growth bill would come down” [32]*

A number of pre-Upkeep surveys are undertaken, including a Pre-Upkeep Material Assessment (PUMA), which is normally undertaken 12 months prior to Upkeep. However, during this period a vessel will invariably perform a deployment with consequential wear upon systems. Unlike commercial shipping who will typically operate to fixed itineraries, e.g. Maersk (ME1) departs on Saturday from Felixstowe and arrives in Jebel Ali exactly 28 days later [33], maintaining scheduled loading / unloading dates at an optimum transit speed. Naval vessels operate over a range of speeds (Fig. 1) and perform a variety of tasks.

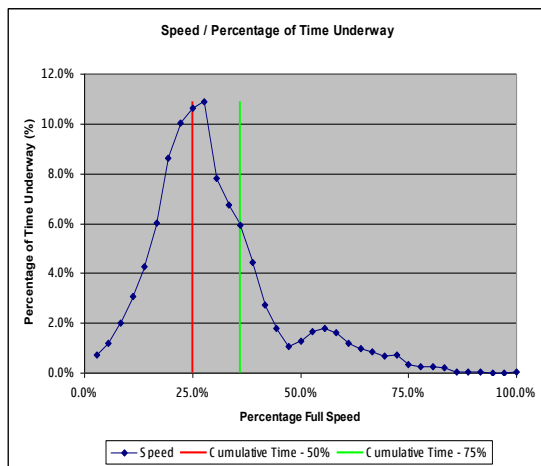


Fig.1 Ship's log (S322) data from 5 RN vessels 2009-2010

The PUMA may not reflect the actual state of the vessel prior to Upkeep. The risk of project growth and potential delay in vessel availability as a result of emergent work and variation orders is extremely high. The work package growth for a "Fleet Time Support Period" may be more than 50% compared with the standard estimate.

An organisation will endeavour to minimise risk in the future by Learning From Experience (LFE); by the capture and utilisation of information, experience and tacit knowledge.

*"LFE, that's one area where we're trying to incorporate more and more LFE, because we do repeat projects here, ... but that's quite difficult to capture, evaluate and implement"* [34]

*"Are we using LFE from previous, yes we do a bit,..."* [35]

An additional risk to maintenance is the complexity of the artefact: "the reliability of a system decreases when the number of components increases [36], i.e. the complexity increases" [37]. Naval vessels contain a substantial number of unique and complex systems with associated issues regarding support, spares, system knowledge, testing, integration.

Naval vessels conform to national and international marine and environmental legislation, e.g. MARPOL (Marine Pollution). In addition to performing maintenance to promote environmental sustainability [38] failure to comply with protocols and legislation would inhibit littoral operations and constrain RN vessels to operate only in international waters.

*"All reasonable and practical maintenance measures are taken to minimise the impact of military activity has on the environment"* [38]

It should be noted that within a naval domain, minimising discharges also reduces the potential of detection.

As indicated, the range and scope of risks that impact upon systems and vessels in a naval domain are extensive and reflect the dynamic operational / functional environment.

#### 4.2. Materiel

Defence Equipment & Support (DE&S) has a £14 billion annual budget to buy and support all the equipment and services [39]. Inventory forms part of the budget; the value of the MoD inventory is substantial; at the end of December 2011 the value was £40.3 billion (the gross value without adjustment for depreciation). Inventory spending in 2010-11 was £2.9 billion and was forecast to spend between £1.5 billion and £2 billion each year for the next five years [40].

Preventive and corrective maintenance of a system is affected by the availability of spare parts, adequate facilities, trained personnel, special tools and equipment" [41]. As part of the overall systems lifecycle, logistics and its related support infrastructure must be considered a major element of a "system" and not as a separate and independent entity to the maintenance activity [42]. This would be consistent with Blockley who stated, "systems thinking is about joined up thinking" [43]. Certainly by means of providing the right spares at the right place at the right time, it is possible to reduce the risk of unavailability [44]. However, this is often counter to the experience of RN maintainers,

*"Most problematic, it does vary from day to day, normally we find out what's wrong relatively quickly, I would have to say probably availability of spares. Because a lot of the time we know what's wrong, we know to fix it, but it's not held onboard, it's not on the shelf and there's a long pause to get it."* [45]

A number of domain specific constraints exist, including operational, geographical, unique equipment / systems,

*"The ship lost a significant period of time on task while waiting for additional main engine stores to be delivered into theatre"* [46]

During Upkeep the (non) availability of spares is also a persistent issue,

*"re-building port main engine, 24,000 hourly overhaul, had part problems from day 1, not the right parts, man coming to help us, found more parts needed..."* [32]

*"OpDef raised as unable to complete 6M [month] SE [Safety/Environment] maintenance owing to unavailability of stores"* [47]

In addition to the non-availability of spares, their obsolescence is an issue. British Standard 62402 defines obsolescence as either, (a) transition from availability from the original manufacturer to unavailability, (b) permanent transition from operability to non-functionality due to external reasons [48] and may relate to repairable items, non-repairable items, information, skills. Given the longevity of complex naval assets this may be experienced by all classes of vessels.



*“non patt[ernised] cable still not received due to item obsolescence. GTG [Gas Turbine Group] still investigating alternative supply whilst SS [Ship Staff] use old cable.”* [49].

DE&S are endeavouring to manage the obsolescence issue, *“I want the contractor to look at obsolescence, not every week but every quarter, give me an obsolescence ‘heads up’ to say that certain items are now obsolete or potentially go obsolete in 12 months and what do I want to do about them”* [50]

Within the rail industry the change from mechanical to electronic / digital signalling systems highlights an issue with respect to obsolescence,

*“as we kind of modernise and computerise things, the turnaround time between a system being installed and then becoming obsolete is becoming quicker ... whereas mechanical systems, some of which are now 110, 120 years old, there is sort of an expected life of a newer signalling system, say computer interlocking of 22 years,”* [21]

Similarly, the rate of change in computing raises obsolescence issues with airlines,

*“I have a whole pile of aircraft out there that have Pentium 3 chips in them, I have a whole pile of modification over there that require Pentium ... It’s going to cost me £1million an aeroplane to change these chips to do this mod. So yeah, obsolescence is horrendous ...”* [20]

Where spares / material is a particular issue, OpDef signals may be assigned a status of NAAIHTO [Not Available Anywhere In Hand To Obtain]; the non-availability of spares can vary with class, e.g. *Class-P* 3.3%, *Class-R* 10.1% (Sep/2014 ~ Jan/2015).

Obsolescence may arise for a range of influences including national & international regulatory forces, e.g., environment legislation, continuous developments of new components [51]. In the worst case, spare parts may be unavailable owing to obsolescence resulting in entire systems needing to be replaced [52]. Within the naval domain, advances in technology particularly with respect to weapons and sensors will often result in upgrades, known as “Alteration’s and Addition’s” (A&A). However, the content and maturity of the A’s & A’s was raised,

*“I should have a spec. delivered A&A, delivered guidance here and I don’t. I get half, 60% if I’m lucky, ... on one job, our biggest job and we haven’t even got the definition”* [32]

The lack of a detailed specification will have a consequential impact upon the project and subsequent maintenance.

The opportunity to reduce project timescales by holding stock items was raised on numerous occasions,

*“I think in the current climate you don’t order them until you know which ones you need and so forth, but actually you could have a stock on the shelf and that would assist your surge capacity”* [53]

A consequence of such a large volume of emergent work is the inability to utilise techniques such as Kanban, whereby minimum inventory is held but necessitating detailed material planning, often the antithesis of naval maintenance.

The Platform Specific Consolidated Allowance List (CAL) is an onboard material allowance formulated for the reduction in the number of days lost due to OpDef’s and to produce optimum support whilst balancing cost. Composition and availability of the CAL and actual subsequent usage is often a source of contention,

*“I’m never very satisfied with the amount of stores we can carry onboard, rarely we have a defect at sea we identify the stores and we happen to hold it in my opinion”* [17]

*“the DLO [Deputy Logistic Officer] said to me, 20% of OpDef items that required stores support were rectified by items on the CAL”* [2]

Problems with the CAL have also been highlighted within OpDef’s,

*“Historically held onboard, CAL change in 2009 dropped allowance from 3 to 0”* [54]

*“Not on CAL. Yes should carry”* [55]

A lack of equipment / stores availability may result in a STOROB [Stores Robbery], i.e. the removal of a ship’s fitted equipment (or parts of it) for installation in another. The Secretary of State for Defence declared this should be, “used only as a last resort to meet high readiness operational commitments” [56]; however, STOROB is frequently used to resolve non-availability of spares.

*“Early in build, one of our gas turbines was removed for [HMS] Daring after hers was damaged. The list of major items was sufficient to fill the back of a T-shirt with the jaunty line ‘The Last, the Best, more sea-time than the Rest’; claiming tongue in cheek that most of our kit was already at sea in the other ships of the Class”* [57]

Far from an option of “last resort”, STOROB is a standard OpDef status, e.g.

*“Fwd Diesel Generator Out Of Action ... STOROB action. 100% loss of blackout recovery.”* [58]

#### 4.3. Suitably Qualified & Experienced Personnel

The number of engineers (Air, Marine & Weapons) within the RN is 10,140 [59] and represents almost 44% of the total RN full time strength. The number may appear significant given the number of vessels, however, the total number masks shortages in particular roles and specialism’s.

*“a shortfall of 195 marine engineers – some 35 per cent of the fleet – and 175 weapons engineers, or 45 per cent. There is a shortfall of 60 nuclear watch keepers, equivalent to 15 per cent of the full-strength.”* [60]

The availability of Suitably Qualified & Experience Personnel (SQEP) was highlighted as an issue in each functional phase. During Regeneration and Tasking the non-availability of RN maintainers is a critical factor in the maintenance of systems and the sustained provision of OC. Where a post is vacant, the RN / MoD use the term “gapped”,

*“in the absence of the gapped MIG section head, the M1 Group Head and MIC Section Head whilst having a basic knowledge of the systems were unable to diagnose beyond the basic.”* [61]

Gapping within the submarine service is less of an issue, as requisite staffing is a requirement for safe operation,

“certainly on the ME side they said we’re not allowed to be “gapped” which you can do on surface ships.” [27]

The absence of maintainers impacts the level of knowledge and experience as well as increasing the workload for remaining staff. “Gapping” increases dependence upon OEM’s and maintenance organisations and potential delays as a result of unscheduled requests for assistance.

“due to slow provision of OEM advice SS were delayed in defect diagnosis ... The proposed repair plan is to request assistance from OEM to support SS limited ability to diagnose faults fully. SS knowledge exhausted.” [61]

Increasingly OEM’s and maintenance organisations are required to assist vessels whilst deployed,

“OEM assistance required to diagnose defect. Program changes delayed OEM arrival to assist.” [54]

The consequence of increased dependence upon OEM’s support is a lack of system knowledge and capability / confidence within RN / MoD staff. During Upkeep, the lack of SQEP was also perceived as an issue,

“people aren’t SQEP’d enough and that’s no disrespect to anybody... we’re not breeding enough SQEP through-out” [32]

Within the rail industry a similar problem exists, when discussing SQEP, “And enough of them, it’s no good needing ten, but we only have three.” [21]

Maintenance cannot be undertaken without an adequate number or trained personnel [41]. A lack of SQEP will constrain corrective or preventive maintenance..

## 5. Conclusion and Next Steps

This paper highlights a number of issues, i.e.

- a. RN vessels promote and realize Maritime Doctrine; accordingly a vessel can be re-tasked with immediate effect with a change in role, geographical location, threat, etc... with consequential impact upon system operation / usage / load.
- b. Given the scope and duration of operational roles, RN vessels maintain a high level of self-sufficiency and carefully manage each of the factors detailed above. Self-sufficiency is particularly relevant with respect to submarines that maintain the UK’s CASD and remain submerged for 3 months.
- c. The RN has recognised many of the issues identified and have initiated the development of a Naval Engineering Strategy [62, 63, 64] known as Project Faraday, to be led by the Chief Naval Engineer Officer. The objective being the delivery of engineering capability by proactively managing personnel, training, information, etc. within the engineering domain. Project Faraday will endeavour to resolve the issues detailed. Similarly, it should be noted DE&S are making significant investments in a new Inventory Management Operating Cluster to tackle inventory demand planning, supply and management.
- d. Naval platforms are a complex system of systems, which over time will suffer obsolescence; a managed

life extension programme for Type 23 Frigates is currently in hand. [65, 66]

- e. The RN when compared with a power company, rail infrastructure and Europe’s largest regional airline would appear to exhibit a number of similarities, e.g. nuclear technology, artefact longevity, safety,... however, the differences would appear to outweigh any similarities, e.g. risk aversion, modus operandi.
- f. In recent years (2001~2015) the MoD has experienced real term budget cuts [67] with further possible reductions for 2016/17 [68]. The consequence has been a reduction in manpower and increasing pressure on maintenance budgets.
- g. The physical environment and operation is often outside the original design scope and hence the Failure Mode, Effects and Criticality Analysis is potentially not valid or applicable, necessitating the application of “engineering judgement” and the associated risk to personnel and system.
- h. As detailed above, there exists a considerable number of disruptive forces that effect the OC of RN vessels, e.g. risk, SQEP, materiel, however, the durability and sensitivity of the RN, DE&S and the Surface Ship Support Alliance support capability is such to respond to each “force” in the most appropriate manner.

Current research in improved knowledge and decision making is investigating lexical analysis of OpDef’s. The data contains information that is considered high value [69]; furthermore, it provides information to various stakeholders with varying requirements, i.e.

- a. ODH / CODH: limitations upon operational capability.
- b. PDH: (i) “immediate” rectification and restoration of capability (ii) maintenance / upgrades undertaken during Upkeep for the purpose of increasing system / equipment availability.

Lexical analysis research of OpDef’s is intended to investigate two questions, (i) determine the normality of a defect with respect to existing defects, (ii) undertake sentiment analysis of OpDef signals.

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