CONTROLLING THE ROYAL NAVY'S QUEEN ELIZABETH CLASS AIRCRAFT CARRIERS

ABSTRACT

This paper provides an overview of the Integrated Platform Management System (IPMS) being provided to the UK's Queen Elizabeth (QE) Class Aircraft Carriers. The overall platform control requirement for the IPMS is summarised, followed by a description of the system architecture, with particular emphasis on operability and survivability.

The benefits of using a commercial automation system as the building blocks of a Distributed Control System in a Naval Environment are discussed. The individual functional elements of the system software are also introduced. Specifically, how the components of Electrical Power Control and Management System (EPCAMS); Machinery Control and Surveillance (MCAS); Damage Surveillance and Control (DSAC), Condition Monitoring (CM); and the Platform Onboard Trainer (POBT) are fully integrated into one solution. A focus is applied to DSAC, describing the unique features of the L-3 Communications product.

Finally, a description on how IPMS integration is planned to be achieved is provided and how this will lead to risk reduction for the overall project.

KEY WORDS

Integrated Power Systems (IPS), Ship Control Systems, COTS Hardware in a Marine Environment, Distributed Control Networks, Classification Society Rules in place of Mil Spec, System Integrity and Fault Tolerance, Distributed Control Networks .

1 INTRODUCTION

A UK Strategic Defence Review (SDR) in 1998 announced plans to replace the ageing British Royal Navy Invincible Class of Aircraft Carrier's with two larger, more capable vessels. For the manufacturing phase of the project the Aircraft Carrier Alliance, a co-operative relationship consisting of the UK Ministry of Defence, BVT Surface Fleet, BAE Systems Marine, Babcock Marine and Thales UK was formed. Noting the extensive integration required to lead the Power and Propulsion component, Thales UK signed a 'Sub-alliance' agreement with Rolls-Royce Power Engineering, Converteam UK and L-3 Communications Marine Systems. This innovative approach is instrumental in bringing these leading companies together to present a collective agreement with a single common objective.

The new Aircraft Carriers, now designated as the Queen Elizabeth Class, will be approximately 60% of the size of the US Nimitz Class, but, importantly, with only 20% of the crew. This dramatic reduction in manning is partly achieved by the extensive reliance on automation, provided by an Integrated Platform Management System (IPMS). This mandates one of the largest and most complex platform management systems ever to go to sea in a Naval vessel.

The IPMS has been designed to meet the demanding requirement of a large ship, being operated by a limited crew, in all operational warship contexts. The system sits in the high level functional requirement, 'Manage Platform'. Achievement of this function, with the solution is shown in Figure 1.

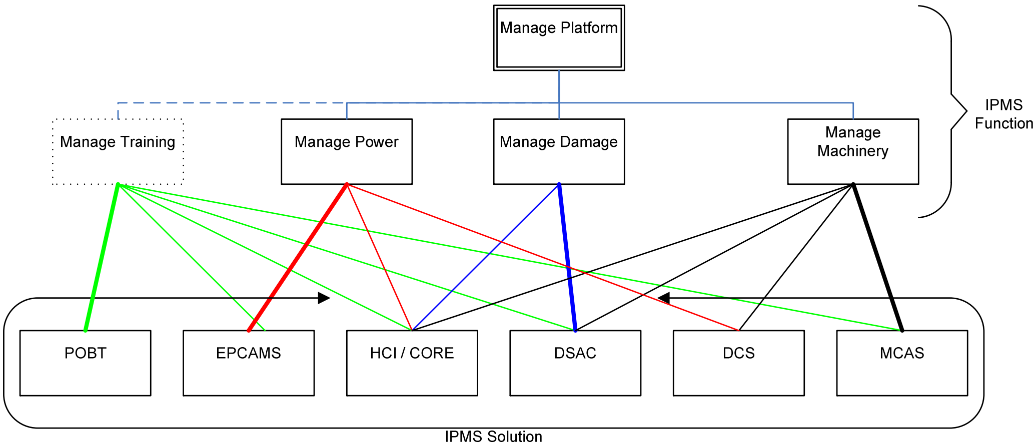


Figure 1 - IPMS Functional Diagram

2 SYSTEM OVERVIEW & CONTEXT

The Distributed Control System (DCS) collects around 30,000 external I/O, feeding up to ~65 consecutive operator workstations. The heart of the system is the unique L-3 distributed software architecture (known as CORE). Performance of the system must ensure control output and display of all information at each operator station within two seconds of any change occurring, wherever the change is initiated from. An indication of the extent of the system is shown in Figure 2 below.

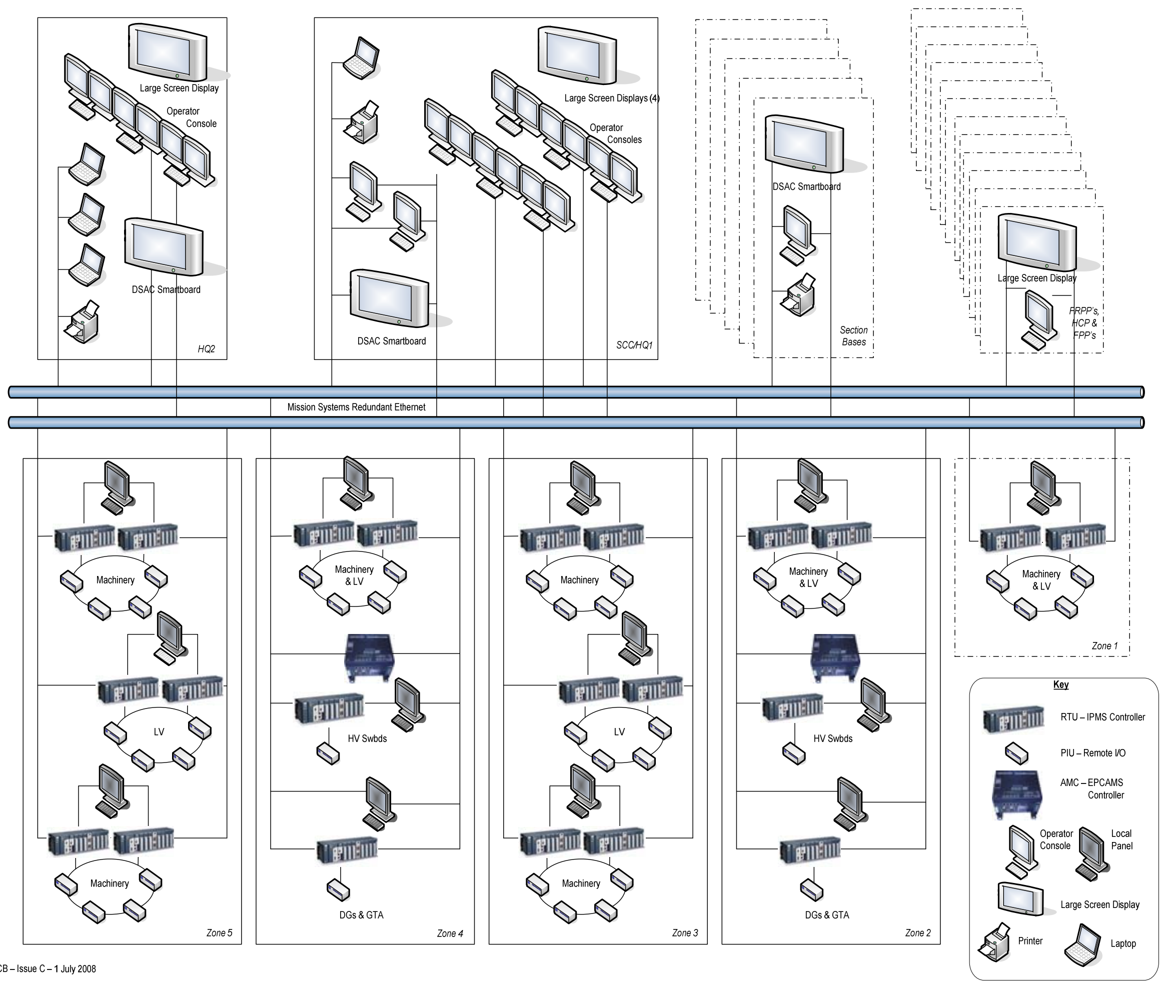


Figure 2 – Indicative Whole-ship IPMS Architecture

2.1 Manning

A key requirement of the IPMS design is the ability to operate such large vessels with approximately the same crew size as their predecessors, the Invincible Class, which are about a third of the size. An enabler in meeting this requirement is the extensive use of automation for both normal operation, and in emergency and action conditions.

IPMS must enable operation of the Propulsion and Marine Engineering systems at the lowest readiness state, by as few as two people, or, in the highest readiness state (Action State 1), by as many as sixty-five. Although a significant amount of Operability Analysis has already been completed, further work is still ongoing in support of the Human Computer Interface (HCI) development. This is to ensure that individual operators have all of the information that they require in support of their potential roles and tasks, across the differing operational situations.

Primary control of the ship's platform and propulsion systems is achieved through the Ship Control Centre (SCC), which combines the functions of Machinery Control, Damage Control (DC) HQ and the Weapons Section Base. The QE Class are divided into five main interconnected control zones along its length for survivability, with the hangar providing a sixth zone. Each of the ship's main DC zones has its own Section Base, and two Fire and Repair Party Posts (FRPP), with each location being provided with IPMS control stations according to the location's manning and function. The hangar also contains a dedicated Control Position (Section Base 6) and two Fire Party Posts (FPP) with access to IPMS.

An alternative Damage Control HQ (HQ2), Weapon Section Base and, uniquely for a UK Warship, a dedicated central alternative Machinery Control Position (Alt MCP) is also provided in the event of evacuation of HQ1.

For machinery control purposes there are also local operating positions for reversionary control situated in the ship's machinery spaces. These reversionary positions provide control for Power, Propulsion and Auxiliary Machinery, in the event that central control is unavailable. In both the SCC and Alt MCP operating positions the operator has direct access to native EPCAMS, should IPMS fail.

Each of the some 65 operator stations provides full access to all aspects of IPMS, to provide control authorities in compliance with the various operational contexts. These fixed positions are supplemented by the provision of twelve dedicated IPMS Laptops and a number of IPMS Network Access points that can be used to expand the access to the system where fixed stations are not available.

2.2 Operational Contexts

A key element in the early systems engineering work for the QE Class was the scoping of all the operational contexts in which the vessels must operate. These include being shutdown alongside, to normal cruising, replenishment at sea or flying stations. Each configuration required the examination of separately identified manning profiles, with different personnel manning multi-function consoles. The consoles are configurable to the specific operator role for the specific context.

2.3 A Networked Ship

The QE Class are completely networked ships and IPMS is one of many electronic systems that will be provided. To support the ships operational mission, and to ensure the platform systems are configured correctly at all times to support air operations, the IPMS has interfaces with the Combat Management System (CMS), the Air Group Management Application (AGMA) and a significant number of cameras provided by Visual Surveillance System (VSS). This, along with the many platform, power and propulsion system interfaces, enables real time information relating to the status of systems to be displayed to decision makers throughout the vessel. This interaction with the Mission Systems does, however, require that IPMS be designed, configured and authorised for operating in the UK Secret domain.

The variety of interfaces are illustrated in Figure 3 below, to show how IPMS provides a fully integrated interaction between the platform functions of EPCAMS, MCAS, DSAC and POBT; whilst also providing the principal means of interaction with other external ship systems.

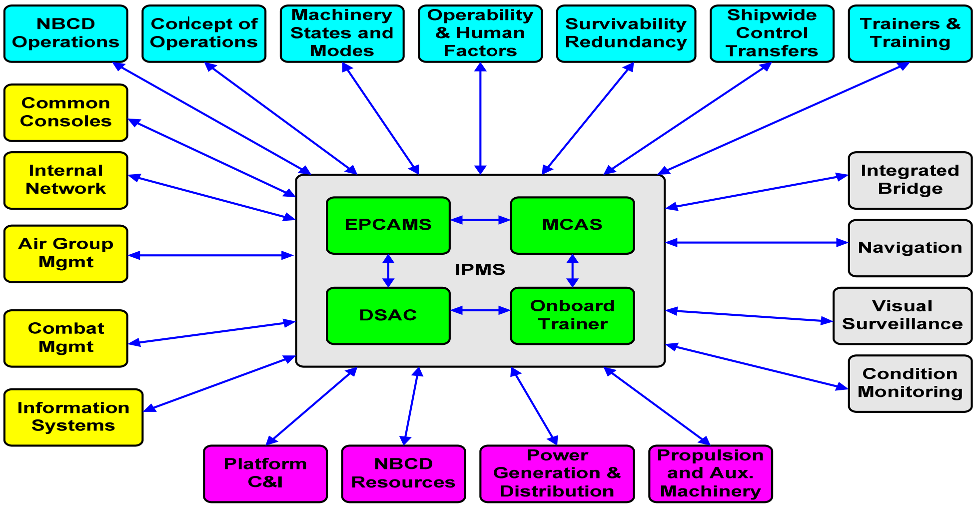


Figure 3 - IPMS Interfaces

2.4 Common Network

The IPMS uses a third party supplied network consisting of a Blown Fibre Optic Plant (BFOCP) and Internal Network Electronics (INE) to provide interconnectivity across the Platform. The BFOCP provides physically protected microducts in which fibre is blown. INE switching is provided at equipment and at individual Node Rooms. The IPMS real time network is an Ethernet/IP network running at 100Mbs below Node Room and 1Gbts between nodes.

Within the IPMS Network a protected sub network, specifically for high speed EPCAMS related communications is provided. This sub network provides communications between the Drive Programmable Logic Controller's (PLC), the Converters and the Advanced Micro Controllers (AMC). The sub network protects these essential propulsion elements from performance degradation potentially caused by general network traffic.

These various interfaces are illustrated in Figure 4 below. The figure shows how IPMS provides a fully integrated interaction between the platform functions of EPCAMS, MCAS, DSAC and POBT; whilst also providing the principal means of interaction with other ship systems.

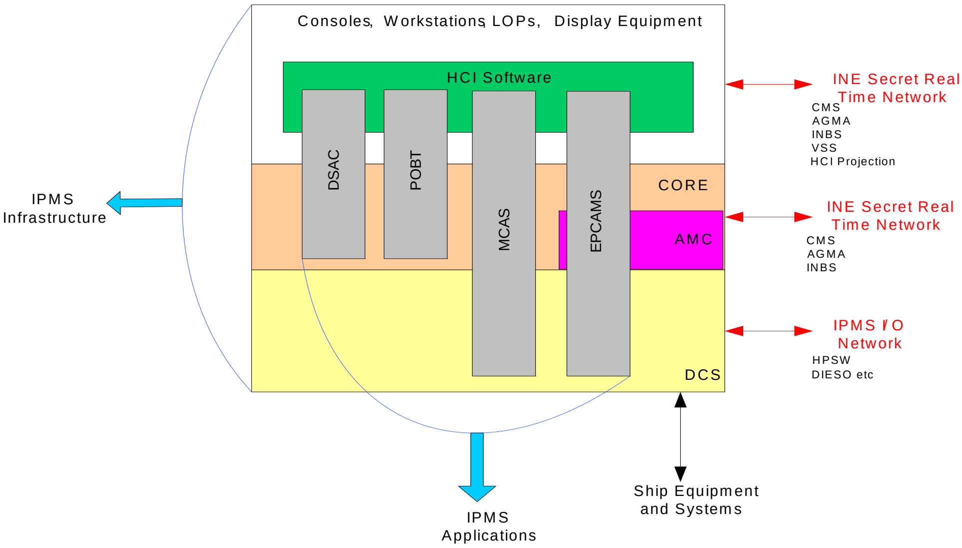


Figure 4 – IPMS Simplified Interface Diagram

2.5 *Common Picture*

The ship wide network and integration with external information systems necessitates that IPMS operators, including the Command teams, have access to a common picture. This facilitates more effective decision making when dealing with incidents, by providing the individual IPMS stations with access to the same real-time information. The flexibility of providing this common real time picture at all workstations also means that operators are not reliant on any one single operating position. Instead they can log in at any of the operating stations to obtain the control and monitoring information that they require for their role.

2.6 *Survivability*

The L-3 proprietary CORE software technology enables the IPMS to meet the demanding requirements outlined above. CORE is a Peer-to-Peer architecture and is the discriminating feature of L-3's approach to naval automation. This architecture provides a complete and synchronised copy of all system information at every one of the operator stations, ensuring the greatest redundancy in supervisory control. Instant access to the latest shipwide system status is a fundamental feature and CORE also provides a means of graceful degradation in the event of damage by avoiding the introduction of single points of failure, such as common servers. This ensures that even in the event of damage, or loss of INE network connectivity, individual areas of the ship, and indeed IPMS stations, can continue to function autonomously.

3 HARDWARE COMPONENTS - COTS vs Mil SPEC

Whilst IPMS has been designed to Lloyds Register Naval rules, a key component has been the selection of Commercial Off the Shelf (COTS) hardware for both operator stations and machinery interfacing. The solutions are designed to reduce the reliance on Military Specification (Mil Spec) hardware and so expand the market place opportunities for competition to achieve the lowest procurement, through life-cost, obsolescence management and to ease future update.

To provide a level of assurance in design, the hardware chosen has to meet the requirements of Lloyds Naval Rules 2005 (tailored specifically for the QE Class Carriers). Whilst the overall hardware solution meets Classification Rules, Type Approval of entire assemblies is not being sought. However, at major electronic component level, most of the components are Type Approved by Lloyds, or an equivalent Society recognised by Lloyds.

The data acquisition electronic solution is achieved using the GE Fanuc RX3i Series COTS PLC technology, that have been encased in bespoke, commercial specification enclosures designed to meet Classification Society design rules The internal electronic components of the data acquisition enclosures are all Classification Society type approved.

The operator workstation electronics are based on rugged marine grade Personal Computers (PCs). Although the suppliers of the PCs, and the Displays and Keyboards fitted to them, are still to be finalised, the requirement for them is Classification Society type approval. However, other IPMS specific HMI electronics, such as the Large Screen Displays and Printers will be pure COTS items requiring only commercial CE Marking.

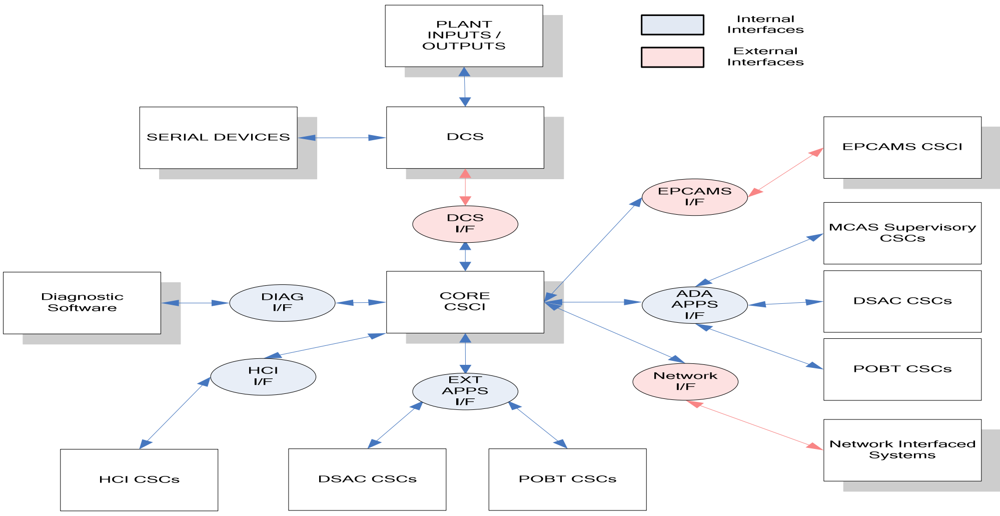
In order to reduce the risk of obsolescence of the HMI electronics, procurement will be delayed until just prior to onboard set to work. The COTS based Consoles and Local Operator Stations carcasses will still be manufactured to meet the ship build requirement, but installation of the workstation electronics will be just in time for the commencement of the ship commissioning activities.

4 SOFTWARE COMPONENTS

4.1 *CORE*

The heart of the IPMS is the CORE software which handles significant levels of data in the system and from where most of the Control Sequences are derived. CORE resides in each of the IPMS Workstations and LOPs; each instance of it communicating to all other CORES in the IPMS system via the Ships internal network. This communication ensures that each CORE remains in synchronisation with the other instances at all times. CORE enables operators to have the same control and monitoring functions available from any workstation.

The broad scope of CORE is shown at Fig 5 below.



CSC – Computer Software Component

CSCI – Computer Software Configuration Item

Figure 5 - CORE Interfaces

4.2 MCAS/EPCAMS/CM Integration

MCAS forms the backbone for data collection from marine systems installed in the QE Class Carriers, providing control and monitoring for some 46 separate systems. To achieve this, the CORE software interfaces with the COTS DCS system.

Unlike previous IPMS systems used in the Royal Navy, the Converteam supplied EPCAMS system will be fully integrated into a single IPMS, providing operators with a completely seamless and transparent solution. The EPCAMS element is a derivative of existing solutions, and this provides the benefit of significant pull through of a system already in service with the Royal Navy.

Whilst the core components of IPMS (MCAS/EPCAMS/DSAC) are all integrated, the QE Class will use the Ministry of Defence (MoD) standard Condition Monitoring (CM) application provided by James Fisher MIMIC (JFM). Approximately 200 rotating machines, deemed to be mission critical, will have permanent vibration transducers connected to IPMS. The data from these transducers will use the IPMS DCS Remote Terminal Unit’s (RTU) as the connection point to the INE network, to enable the data to be transferred to the CM Software that will be hosted in one of the IPMS Servers. Other equipment will be monitored for Vibration by using hand held recorders, with the data collected being downloaded to the MIMIC software.

There will be 2 instances of MIMIC in the ships. One instance will be located on the Restricted INE to interface directly with the ships Upkeep Maintenance Management System (UMMS). The second will be integrated into IPMS, which is hosted on the Secret INE. Due to Information Security (INFOSec) requirements, it is not possible to have a direct link between a Secret and Restricted network, therefore transfer of the data from IPMS MIMIC to the Restricted MIMIC will be via an air-gap using hard media, such as CD. The IPMS MIMIC has CESG approved software to ensure only Restricted data is transferred from the Secret Network.

Like many aspects of IPMS in QE Class, the CM system is one of the largest that JFM have so far produced.

4.3 DSAC

The challenge of assimilating and prioritising the activities of the ship’s damage control teams is vitally important to the successful implementation of the IPMS. This has to be done across the various section bases and repair party posts, and is essential to the overall survivability of the ship. The QE Class DSAC is an extrapolation of L-3 Damage Control solutions already developed and implemented for some 20 naval customers. The solution incorporates the latest Royal Navy specific functionality and requirements, based on the Damage Control solutions already at sea onboard the Royal Navy's Landing Platform Dock (LPD) Class. The solution is extensive pull through from existing solutions, supplemented to include specific requirements for the QE Class Carriers, captured from the tailored DSAC Naval Defence Standard 08-111 baseline.

The CORE peer-to-peer architecture ensures that all Damage Control stations instantaneously display the current version of the operational picture when updated data is input at any station. It also ensures that if communication with any other station is lost, that the station will retain the last updated status. Of particular interest in DSAC are the following innovations that will go to sea as part of the QE Class Carrier IPMS Damage Control solution:

i. Pan, Zoom and Overlay

Damage Control functionality is implemented using a layering technology whereby data is captured and displayed on up to sixty separate display layers. This permits de-cluttering at the overview General Arrangement Plan (Incident Board) level of data display. This feature permits the addition of increasing levels of detail during a zoom into particular areas or compartments of the ship, or by selection of specific layers by individual operators. These layers can be either static or dynamic in nature; dynamic enabling the layer to be updated in real time with the current status of the system.

Schematics of ship fluid and electrical systems will also form overlays which can be placed onto the Incident Board to indicate specific routings and resources.

ii. Smartboard Technology

Damage Control Large Screen displays in the SCC and Section Bases will be supplemented using Smartboard™ Large Scale Touchscreen Technology, to permit direct manual operator interaction with the screen and so ease data manipulation and representation. This ground breaking technology, in this application, will be fully trialled at sea in HMS Albion in order to provide valuable operator feedback and de-risking for the QE Class carriers. Shore based demonstrations of this technology to a variety of stakeholders has assisted in definition of the solution.

iii. Free Draw

Free Draw permits the IPMS DSAC stations, specifically the Large Screen Damage Control displays, to be used as a briefing and planning tool. Using free draw, operators can also insert manual Symbology, or simply free draw onto Damage Control displays and layers, to indicate actual action situations and plan strategies for prosecution of an incident. As explained below, at Advice Mode, these mark-ups can be local to the individual Incident Board during the planning phase and only then transmitted ship wide for implementation once the planner is content with the brief.

The QE Class solution will include embedded re-entry briefing pages for key compartments such as Machinery Spaces and Galleys. DSAC Operators will be able to call these pages up from the Incident Board and then prepare the re-entry brief, utilising free draw, to provide team briefing prior to a re-entry. This feature will replace the need for the manual process that the Royal Navy currently uses.

iv. Advice Mode

As part of the planning and briefing capability, an individual workstation or large screen display can be used for planning purposes, with solutions being generated by the Damage Control Command Team using the Freedraw function in a self contained mode. When a particular solution has been agreed, it may then be broadcast shipwide for action by the Damage Control Organisation. QE Class will have compartment re-entry briefing pages for key high hazard compartments embedded into the Incident Board to allow re-entry planning to be included within the IPMS system.

v. Active Kill Cards

Kill cards traditionally contain compartment information used to inform users what hazards and isolations need to be considered when dealing with a fire situation. Active kill cards are essentially checklists of tasks to be executed in the event of fire or damage to a particular compartment or system. The QE Class Damage Control system is expected to contain up to 10,000 Active Kill Cards detailing the “staff answer” to most eventualities. These kill cards will also contain guidance information including such detail as the correct compartment isolations in the event of fire, system reconfigurations, etc.

As an integrated PMS system, where Machinery and Electrical Plant control is integral with Damage Control, the Active Kill Card functionality can permit direct operator intervention, for example where the operator orders an action to take place from the kill card. Alternatively, sequences can be instigated automatically, where by the kill card itself takes the action directly, without the need for operator intervention. An example of this might be the stopping of ventilation when a fire detector indicates a confirmed fire.

Kill Cards will be customer generated using the L-3 Kill Card builder tool being provided to the QE Class Carriers. As well as the initial generation of the kill cards, this tool will also enable updates to be implemented by the ship’s staff through the life of the ship as the capabilities and layout of the ship change or as the Operating Procedures evolve and operator knowledge increases.

vi. Internal Battle Capability Reporting

Internal Battle Capability Reporting is a Command function which permits the rapid exchange of operational priorities between the Engineering Management Teams and the Command. This is done by the identification of system failures and action damage from the teams on the ground charged with maintaining internal capability. It permits the engineering and weapon’s Command team decision makers to be aware of any capability shortfalls. This enables them to prioritise the required corrective action in accordance with the ship’s overall priorities to meet the ships Command Aim. It thus provides a significant aid to the overall ship capability management.

vii. Stability

Much of the information affecting the stability of the ship is already captured in the IPMS system, either from the MCAS system for tank fluid levels, or from DSAC for aircraft weight and position information, damage and flood information. The MOD Standard Stability Application (Seagoing Paramarine) will be integrated into the IPMS so that real time stability calculation will be available in the event of Damage or significant movement of weights.

4.4 POBT

In common with most major warship projects, the QE Class places a significant emphasis on the provision of an embedded training capability. IPMS will provide a Platform Onboard Training solution that will deliver training in realistic scenarios onboard, even when the vessel is at sea and access to the physical propulsion training resources is usually limited.

Individual Operator Stations, or groups of stations, such as the complete Ship Control Centre, may be put into training mode, whilst retaining actual ship control from alternate positions. This reduces the requirement for extensive shore based training assets, whilst keeping the ship’s crew at a high operational peak.

i. Full Function Simulation Model

A full function simulation model of the main ships system, including Power and Propulsion, permits trainees to interact with an accurate representation of the ship’s machinery and systems and for the model to behave as the real ship in response to trainee inputs such as requests for system reconfigurations, power demands and exchanges of station-in-control.

The same POBT model is planned to provide the backbone of any shore based training facility put into place as part of any pre-joining training courses.

ii. Team Training

The Platform Onboard Trainer will support team training whereby all consoles placed in training mode can interact with the Common Simulation Model and receive a common system picture in response to operator inputs from any one of them.

iii. Instructor Station Capability

The Platform Onboard Trainer will permit an Instructor to supervise the training session, impose a given set of initial conditions, insert system malfunctions and failures or create any number of Lesson Plans which replicate a particular scenario with a specific set of malfunctions and failures which will occur at pre-set times. Lesson Plans can be stored and the system will provide Record, Restore and Playback capabilities. This permits the analysis of trainee performance in response to a given lesson plan.

5 INTEGRATION

5.1 Shore Integration Facility (SIF)

IPMS Integration is a significant risk area, so as mitigation, extensive testing will be conducted ashore at a dedicated Shore Integration Facility (SIF). The SIF will enable a complete system to be configured ashore using hardware from the second ship. Each software component is loaded and checked for correct functionality.

This shore based approach will be used not only to test internal interfaces, but also the many external interfaces to systems and equipments throughout the ship, including both Mission and Platform Systems. Power and Propulsion integration will be further de-risked by testing with representative 3rd party hardware and software, or indeed, plant performance simulations to represent the actual propulsion system. Lessons learnt from previous projects have shown that this approach should significantly reduce risk and make onboard Set to Work (STW) quicker and more cost effective.

Following IPMS integration in the SIF, it is intended that a reduced Reference facility will be maintained ashore. This would enable regression testing in a controlled environment for any Software changes that will occur up to and possibly beyond Acceptance, and into Service.

5.2 Ship Integration

The IPMS team is jointly responsible with the Shipyard Commissioning Teams for the correct performance of both the IPMS and the broader Power and Propulsion Systems through test and commissioning until final acceptance at sea trials. To support this activity the IPMS Team will have embedded IPMS Specialists in the P&P Commissioning Team and a support team at the Reference Facility in the SIF.

6 CONCLUSION

As the drive to reduce manning in Warships continues to gather pace, the IPMS control system must enable fewer operators to safely manage platform systems in all operational conditions. In order to achieve this for the QE Class, one of the largest and most complex IPMS systems is provided.

This fully integrated system will also provide the window to operators for providing real time information on platform systems and, because of the integration with the Damage Control systems, will enable decision makers to operate more effectively, particularly in emergency situations.

Integration to this extent does bring its own information security problems to integrators. These problems have been overcome by use of the common network that supports all of the ship’s other applications and it’s accreditation by the MOD security accreditation organisation (CESG).

The hardware solution is a departure from the Military Specification hardware used in traditional Naval projects. The solution uses of a mixture of Classification Society Type Approved components, pure COTS components and bespoke commercial specification enclosures. This has been designed to reduce the reliance on Military Specification hardware, reduce procurement cost and it will expand the market place opportunities for competition to achieve the lower through life-cost, obsolescence management and ease future updates.

The shore based integration activity (SIF) will be used to prove IPMS and its interfaces prior to installation into the ships. This is a significant risk reduction activity and its use for regression testing in the latter phases and after Acceptance should provide a useful through life facility.

7 AUTHORS BIOGRAPHY

Jim Davies: Since March 2006 Jim Davies has worked in the IPMS Engineering Team of L-3 Communications Marine Systems UK. Prior to joining the L-3 team, he was a Commissioned Marine Engineer in the UK Royal Navy (RN) where he served in various sea going and shore appointments in a career spanning 34 years. Jim is a subject matter expert in Damage Control and Firefighting techniques used by the RN and is now the Project engineer, leading a team of specialists tasked with delivering a fully integrated platform management system for the RN Queen Elizabeth Class Aircraft Carriers. Jim can be reached at jim.davies@l-3com.com

Stuart Jewell: Stuart Jewell has been the IPMS Delegated Design Authority since August 2007. Prior to that Stuart was responsible for the design, assurance and acceptance of the PMS for the Auxiliary Oiler class tankers, the first MOD owned vessel to be procured with a PLC based control system. Stuart has had a career of 22 years within the naval sector of the UK Ministry of Defence with previous responsibility for the support of machinery control systems on T42 Destroyers and the current Invincible class carriers. Stuart, working within the Thales area of the Aircraft Carrier Alliance leads a team of 8 automation experts to deliver the QE Class IPMS. Stuart can be reached at stuart.jewell@uk.thalesgroup.com