HUMAN SYSTEMS INTEGRATION ON PLATFORM MANAGEMENT SYSTEMS

BY

Ian SCOTT
(*DLO MLSIPT*)
Tex CRAMPIN
(*Liveware)*

This is an edited version of the paper that was presented at the Human Systems Integration Symposium *held in Arlington Virginia in June 2005*.

ABSTRACT

The view of the warfighter is often,

> "Those that fire the missiles, fly the planes or direct the guns".

Very seldom does the image reveal one of the engineer controlling the plant that,

> "Supplies the power to support the radar, launch the plane or rotate the gun".

But without these services the ship could neither fight nor survive. The provision of Platform Services is central to the fighting ability of the ship.

The integration of platform engineering systems has historically been accomplished by the ship's company with little assistance from the systems themselves. However, modern warships are coming to rely more heavily on the use of integrated system controls, the so-called Platform Management System (PMS) that becomes the common 'face' of the many control and automation systems onboard. The PMS is now capable of performing many of the 'management' functions formerly the domain of the crew.

The integration of the Human System with the PMS now drives efficient and effective control of the Platform Engineering functions onboard and thus becomes the lynchpin in supporting both external and internal battles.

This article presents a view of the work the UK MoD Marine Electrical Systems Integrated Project Team (MLSIPT) have done in the area of Human Systems Integration on PMSs. It will concentrate on the area of Human Machine Interface (HMI) design, from the development of a Control & Display Evaluation Tool based on the Type 23 Anti-Submarine Warfare frigate, through the functional analysis of that solution into practical guidance for the development of future PMS HMI's.

Introduction

This story starts back in 1994 when the need to understand the requirements for a multiple Visual Display Unit (VDU) based Human Machine Interface (HMI) was realized. Up to this point in time the medium for control of the Royal Navy's machinery control systems had been hard-wired bespoke panels (FIG.1).

It was realized that, with the drive to reduce costs and the move to commercial equipment, this type of interface had had its day. The use of VDU or 'glass screen technology' was the way forward.

FIG.1 – TRADITIONAL CONTROL PANEL

In order to ensure that the Human Factors (HF) issues surrounding this new type of interface were understood it was decided to develop a Ship Control Centre Laboratory Facility. The laboratory would ultimately be used to support the introduction of Platform Management System (PMS) glass screen solutions on future platforms but to do this it was necessary to understand the operational issues as well as those to do with technology.

Type 23 Analysis

FIG.2 – TYPE 23 FRIGATE

In all endeavours it is easier to make progress if the starting position is well understood. So it was with this project; the Type 23 Frigate (FIG.2) had been in service for several years and the functionality within the Ship Control Centre (SCC) was well understood. She also had the advantage, as far as this study was concerned, of having her propulsion control from the SCC and not, as on most other current platforms, from the bridge. An analysis of her SCC at State 3, carrying out Machinery Control and Surveillance (MCAS), was seen as a good starting point.

The task analysis

A task analysis is an all-embracing term used to describe six key HF analysis processes:

- Role Analysis providing information on the routines and responsibilities of personnel within the SCC.
- Link Analysis providing information on the interaction and interdependencies of the SCC.
- Functional Analysis to define the systems and match them to the operators required to interface with them.
- Activity Analysis to extend the Role Analysis Operator tasks into individual activities.
- Spatial Link Analysis to assess the geography of an interface with respect to hand/eye motion.
- Time-Line Analysis to ascertain timing limits, logic and workload.

The analysis of the Type 23 SCC was based on 15 tasks deemed 'Mission Critical' by Royal Navy Subject Matter Experts (SMEs). The MCTs covered evolutions ranging from the starting and stopping of Gas Turbines, through various trip conditions to recovery from total electrical failure.

Role Analysis

This part of the analysis was accomplished largely by contact with RN SMEs, who were questioned on the routines undertaken and the role of each member of the SCC team in those routines. This method developed not only an understanding of the individual issues but also the interactions necessary, to add to the ensuing link analyses, that together provided a 'global' picture.

Link Analysis

A link analysis diagram (FIG.3) was drawn up showing the importance and frequency of the communications between the various personnel in the SCC. Data for this analysis was collected as follows:

- A table was created containing all personnel in the SCC in the initial row and column.
- The table was completed by a SME who provided ratings of the relative importance and frequency of the communications between the various personnel.
- The categories used for importance were:

  Critical, Important and Routine.
- The categories used for duration were:

  Frequent, Occasional and Seldom.

	ANBCDO	DCO	Machinery Sup	Electrical Sup	Propulsion Op	Auxiliaries Op	Elec. Sus. Op.	Ballast Op.	Fwd DSAC Op.	Aft DSAC Op.	NBCPOA	Senior Stores	Comms No.	NBCD Mess.	Sec. QM
ANBCDO		C/F	C/F	I/F	R/O			C/O			I/F		R/O	R/O	
DCO	C/F		C/F	I/O				C/O	C/F	C/F	I/F		I/F	I/O	
Machinery Sup	C/F	C/F		C/F	C/F	I/F	I/F	I/O				R/S	R/O	R/S	R/S
Electrical Sup	I/F	I/O	C/F		I/O		C/F		I/O	I/O		R/S			
Propulsion Op.	R/O		C/F	I/O		I/F	R/S								
Auxiliaries Op.			I/F		I/F		R/O	R/S							
Elec. Sus. Op.			I/F	C/F	R/S	R/O									
Ballast Op.	C/O	C/O	I/O			R/S									
Fwd DSAC Op.		C/F		I/O							I/O		R/O	R/O	
Aft DSAC Op.		C/F		I/O							I/O		R/O	R/O	
NBCPOA	I/F	I/F							I/O	I/O			R/O	R/O	
Senior Stores			R/S	R/S											
Comms No.	R/O	I/F	R/O						R/O	R/O	R/O			R/S	
NBCD Mess.	R/O	I/O	R/S						R/O	R/O	R/O		R/S		
Sec. QM			R/S												

Fig.3 – Example Link Analysis Table

Functional Analysis

Analysis of the systems needed by a range of operators soon produced functional groups if more than one operator needed to interface with a system. This functional grouping (Fig.4) gave the first indication of operator requirement in the design of a workstation.

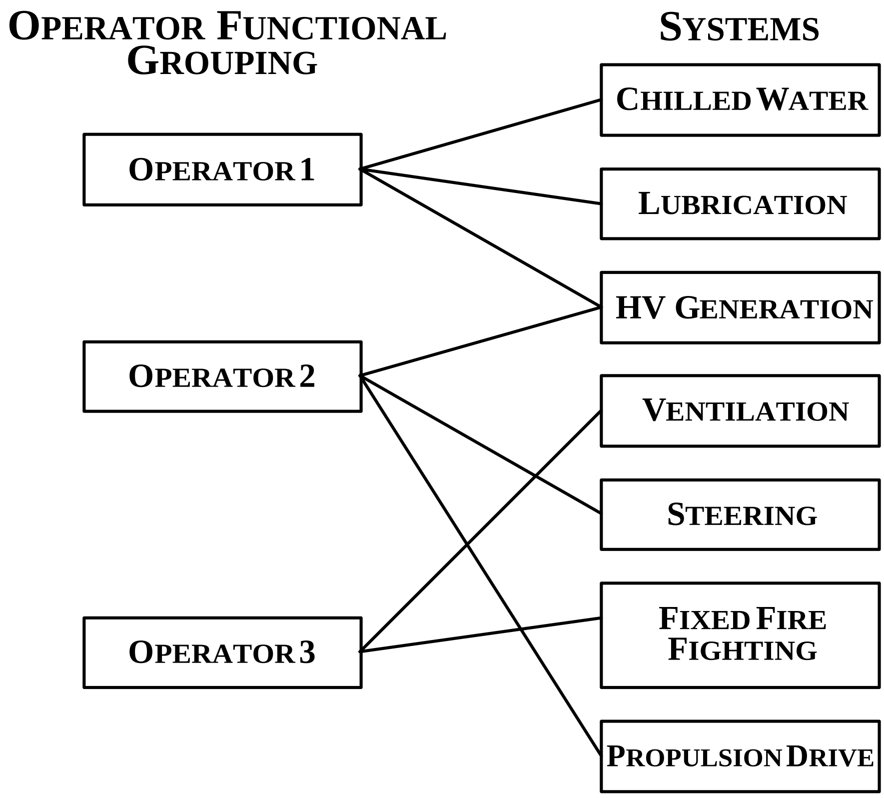

FIG.4 – EXAMPLE FUNCTIONAL GROUPING TABLE

Activity Analysis

Video data was collected for the 15 MCTs at HMS *Sultan* the RN's principal training establishment for marine engineering. Three instructors were involved in performing each MCT. One instructor took on his usual role as the instructor; one instructor acted as the Propulsion Operator while the last instructor assumed the role of the SCC supervisor.

Two sets of data were recorded; one in slow time where the operators talked their way through the procedures to allow in-depth analysis and one which simulated the way in which the MCT would be performed in the real world. The tapes were analysed and activity tables were created showing the following:

- Events; outputs from SCC panels and communications from differing parts of the ship.
- Actions; Supervisor and Operator activities.

Spatial Link Analysis

Further to these tables a spatial link chart was used to create a representation of the operator's eye and hand movements. This was accomplished by the use of an exact replica (not to scale) of the SCC panels and consoles drawn on a computer. Each hand and eye movement could then be shown. This was then used to develop the ergonomics of the new interface.

Time-Line Analysis

A time-line was drawn up for all operator activities. This assisted in defining the logic of those actions, showed time limits where applicable and could thus be used in the assessment of workload.

Supporting Information

The instructors provided information in support of the analysis and filming of the MCTs assisted in the building of the 'bigger picture' which identified the operational issues, systems, related activities and information necessary to perform the MCTs.

Once the analysis had been completed the necessary hardware, in the form of a computer model of a Type 23's propulsion, generation and auxiliary systems, was linked to a multi-screen graphical user interface. The initial development of this interface was a result of the analyses so far; PMS CADET was born.

PMS CADET

The Platform Management System Control and Display Evaluation Tool took the functionality in the Type 23 SCC Machinery Control and Surveillance (MCAS) (FIG.5) and embedded it in a multi-screen solution.

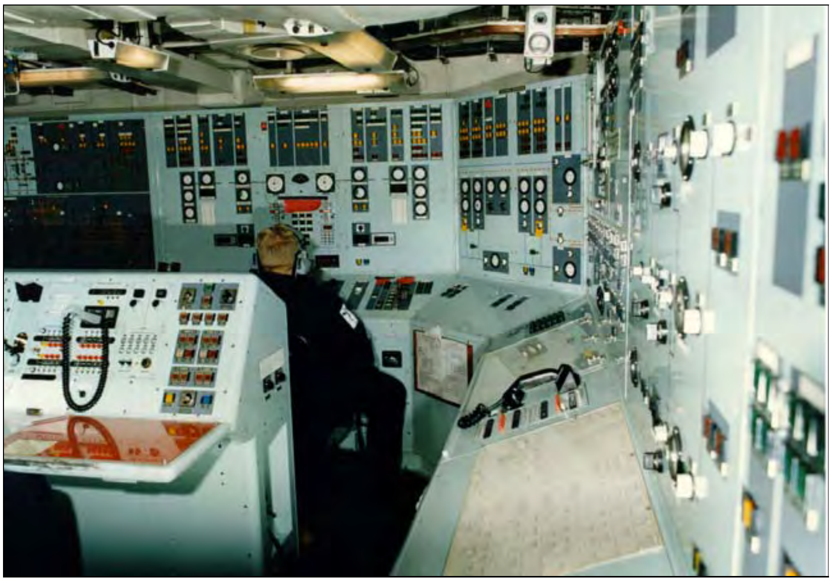

FIG.5 – TYPE 23 SHIP CONTROL CENTRE

What it also did was enhance this by the active use both of the task analysis and good ergonomic design of the screen layouts. The analyses had indicated the need for the interface to supply information at Overview, Primary and Secondary levels. This was accomplished by a multi-screen approach. The resultant workstation allowed a single seated operator to replace two semi-seated operators.

Note:

> The need to access many different systems on the Type 23 combined with the layout of the ship's control consoles means that the operators are only seated for part of the time.

A range of trials based on the original MCTs established the validity of the interface by comparing the ability of the operators to accomplish the tasks without errors and within a similar timeframe as the *Sultan* trainers. The result of the analysis and of the trials confirmed the earlier thoughts on information requirements. The interface provided:

- Overview information via a central VDU.
- Primary system information via two sided VDUs.
- Secondary information via windows within the sided VDUs.

A fourth VDU, providing an Alarm & Warning list, was added after the initial trials.

FIG.6. – PMS CADET

Once the baseline had been established a range of studies used CADET (FIG.6) to explore the Human factors issues around:

- Use of characters and symbols.
- Prompting techniques.
- Increased automation.
- Techniques used for enhancing 'Situational Awareness' in complex situations

Characters, Symbols and Prompts

The aims of these studies were to:

- Investigate the range of acceptable character sizes for different display levels,
- Investigate the use of various prompting techniques in the provision of task based operator assistance

The results of the first trials indicated an optimal character size of 22 arcmin for labels and values and 37 arcmin for titles. This was considerably larger than the Defence Standard (00-25) recommendation of 15 arcmin as a minimum.

The results of the prompting study suggest that the optimal prompting mechanism would be one that provides a voice prompt accompanied by a localized text instruction. The overwhelming assessment of the trial participants was that any implementation would require considerable care and need to be intelligent if anything more than basic training was to be supported.

Increased Automation and Situational Awareness

These studies investigated the facilities required by an operator in very different modes of use. The first considered a submarine control interface where the underlying control system was highly automated with the operator exercising 'Supervisory' control only. The use of two entirely different styles of interface (FIGs 7 & 8) was examined to ascertain the support required by the operator and that given by the interface.

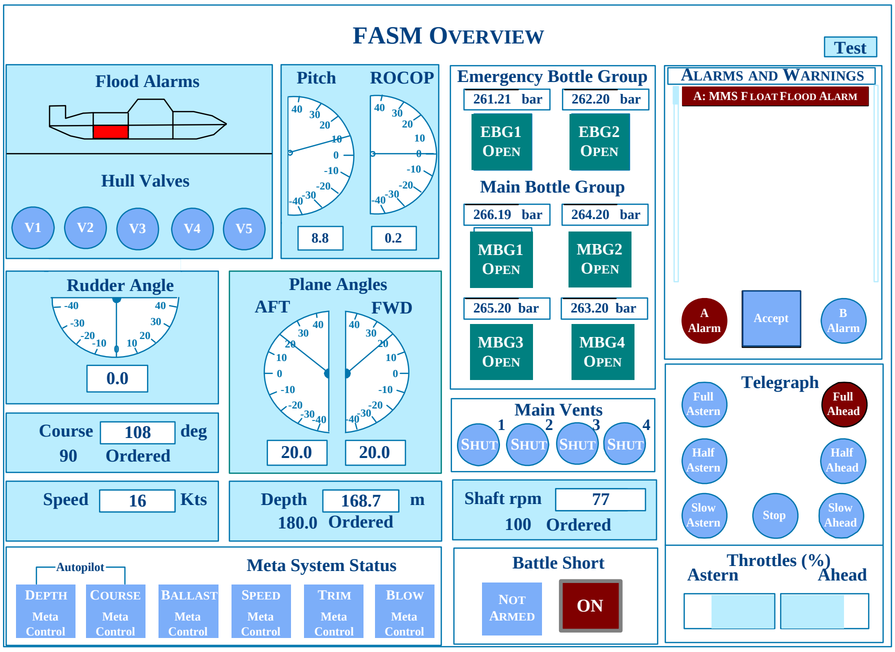

FIG.7 – TRADITIONAL STYLE OVERVIEW

TOP LEVEL TASK DISPLAY

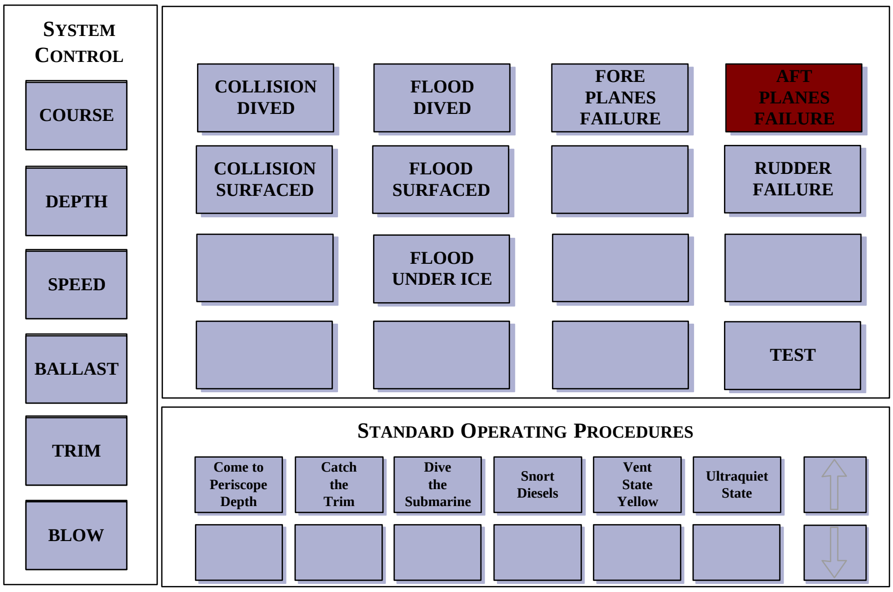

FIG.8 – SUPERVISORY STYLE TOP LEVEL

The second study compared the traditional CADET interface and level of automation with a far more automated model where the execution of whole MCTs could be delegated to the 'machine.' This second interface was enhanced by the provision of an intelligent Alarm and Warning system that prioritized information.

User trials were held in order to assess the benefits of the enhancements compared with the original system.

Three situations were selected for assessment purposes:

- A routine scenario.
- A masking scenario where two malfunctions were introduced with the intention that the second would go unnoticed due to the occurrence of the first.
- A conflict scenario where rectification of one fault condition is prevented either by operational requirements or by a further developing scenario.

The results from these studies showed great promise in establishing the benefits of automated management systems. Initially the 'Supervisory Control' style of interface needed to be supported by very detailed mimics of the systems under control. However this requirement reduced as the operators became more used to the overview and came to understand (and trust) the intelligent Alarm and Warning system.

Greater automation and Supervisory Control appears capable of maintaining safety levels while enabling reduced manning levels and enhanced operational capabilities.

The prioritization of information was viewed with greater scepticism. It was considered only to be practicable for use in support of standard operating procedures, when a 'script' could be employed, or during training. This method would not support more complex or damage situations. A thorough overhaul of the traditional Alarms and Warnings philosophy would need to be carried out in order to understand how intelligent operator assists could be used in these circumstances. The first steps in understanding the characteristics of such a system was carried out by the HCI Concepts study carried out later.

From Theory to Practice

PMS CADET had realized the Type 23 MCAS into a four screen solution and introduced the possibility of reducing watch keepers by half.

No account was taken, however of the impact Damage Control might have. The need to include whole ship or even whole job issues was not taken up and the studies recognized that without these issues being addressed no recommendation could be made about actual crew reductions.

The methodology used to develop the number and design of the screens could be recommended however.

Twin Screen PMS

Whilst the CADET solution was considered, potentially, to be the optimum design for a Type 23 MCAS workstation it was realised that future platforms would not necessarily operate in the same way and may have greater or lesser levels of automation. There was also awareness of the need to integrate the MCAS system with electronic Damage Surveillance And Control (DSAC) Management Systems.

The cost of developing a three or four screen solution for a future platform was seen as prohibitive both for the project teams and for industry. The most likely solution would be the development of the Commercial Off The Shelf (COTS) products, predominately single or two screen solutions, already available. There was a need therefore to explain the requirements for the development of these products in functional terms. This work was carried out in parallel with the Type 45 Anti Air Warfare (AAW) Destroyer PMS workstation design and the methodology shown below was used in the development of that solution.

Concept of Operation

The first and possibly most important consideration in developing a workstation design is the Concept of Operation or use. It is vital to fully appreciate the concept of operation both of the users and the systems that are to be used.

These factors are interdependent; a highly automated system may require very little ‘control’ in an HMI but may need far greater effort put into the design of a ‘maintainers’ HMI. Conversely if the user is an ‘operator/maintainer’ they may need a different HMI to the user who only ever functions as an ‘operator’.

Supervisory Control gives the requirement for the HMI to provide situational awareness of the process being undertaken but, possibly, only sufficient control to allow the operator the power of veto.

For the foreseeable future (build of Type 45 and CVF) it is not considered that the RN will alter its’ watch keeping philosophy i.e. it will maintain a central facility that will be continuously manned at a minimum level and increase that level to meet higher states of activity. The watch keepers act as operators on the majority of systems with a few notable exceptions, e.g. electrical generation, where ‘Supervisory Control’ is exercised.

Number of screens

The development of single or two screen solutions from the CADET four screen one was achieved by classifying each screen element into function. The challenge was then to achieve this, or greater functionality, with less screen real estate. The Type 45 AAW Destroyer, having a similar concept of operation as the Type 23 Frigate, was seen as the obvious target for this exercise. Other constraints, such as the 'Station In Control' (SIC) concept were also considered in assessing the operator's needs.

Once the functionality was identified it became important to 'manage' the HCI design so that the users were not swamped with information that was not relevant either to the role they were undertaking or the task in hand. The need to maintain Situational Awareness (SA) over a range of complex and interdependent systems was also recognized. These requirements were accomplished by analysing the information needs for each operator role using different operational scenarios.

The information needs were classified according to importance, frequency of use and whether the information was required constantly, frequently or occasionally.

The resultant recommendation was the use of two screens each presenting information simultaneously with the information elements sub-classified as:

- Fixed screen elements.
- Role based overview.
- System summary.
- System display.
- Sub-system display.

The user has a left-hand 'overview' screen designed specifically for the role being undertaken. This screen provides:

- Fixed elements showing such information as:
  - ❑ Command Aim.
  - ❑ Threat.
  - ❑ NBC State.
  - ❑ SIC.
- High level situational awareness of systems under control.
- Alarms and Warnings, for those systems the user has SIC of, in textual and geographic context.
- Navigation to system summary or detail pages.

This screen has no 'control' over system elements and is never normally overlaid thus reinforcing the 'working/overview' divide, maintaining wider system situational awareness and avoiding the 'tunnel vision' that can affect operators of single screen solutions.

The user also has a right hand screen through which control, on those systems the user has SIC over, is exercised and surveillance of all systems is gained. This 'working' screen provides:

- System summary pages for complex or large systems.
- System detail pages.
- Sub-system pages accessed via the above.
- Control functionality via pop-up windows.

This screen has no fixed elements for Command Aim, Threat, NBC State, SIC or Alarms and Warnings as this would detract from the operational concept for the interface. It does have elements, however, to allow for Navigation to sub or associated systems thus enabling efficient interrogation for faultfinding.

The sub-screen hierarchy is designed to be wide and shallow allowing information to be accessed with a minimum of screens.

This dual screen solution was tested by what is considered the most taxing scenario for an individual operator:

> Cruising at state 3 with a single watch keeper when a major incident occurs such as a machinery room fire. This scenario requires in a very short and intensive period:
>
> - Changes to the propulsion plant.
> - Changes to the ventilation systems.
> - Provision of fire fighting resources to the Standing Sea Emergency Party (SSEP).

The result of this exercise gave confidence that the dual screen solution was sufficient for the control of the systems and, with the other facilities provided by the SCC such as Incident Board style information via the Large Screen Display (LSD), was the minimum necessary for the user to maintain adequate awareness and control of the whole ship situation until help arrived.

Further HMI integration testing is envisaged including the DSAC package but the dual screen solution, together with the methodology used to obtain and ratify that solution, is seen very much as the benchmark upon which all future RN solutions will be based.

Future PMS Design Issues

During the work on CADET on greater automation MLS realized there were a number of areas that would need addressing if future PMS solutions were to give the functionality their advocates promised. One of these areas was the handling and prioritization of Alarms and Warnings. A study with the specific aim of understanding the major design characteristics including machine, automation facilities and human factors of the Human Computer Interface (HCI) of future PMS was raised on QinetiQ (formerly the Defence Agency Research Establishment (DERA)).

This study was actually carried out by BAE Systems Ltd and provided guidance on the facilities required by a future operator relying on far greater levels of automation than are common now.

The Concept of Operation (ConOp) considered for this study taken was one of operators exercising only 'Supervisory Control' over the systems onboard but with the power of veto. It was decided that, for this to function efficiently, the 'operator' needed to be aware of the important issues but that less important ones should remain hidden thus avoiding overload. To do this the whole philosophy behind current Alarms and Warnings was questioned and thought to be inadequate. A new taxonomy of 'Alerts' was promulgated, based on an intelligent information management system that only 'Alerted' the relevant operator if it was actually necessary.

The change from parameter led design to one where the distribution of information depends on this philosophy can only come about if the data collected can be verified, classified and directed according to a recognized set of categories. Table 1 provides an overview of the five categories in the taxonomy, with some comments and revisions based on the user review

TABLE.1 – *Taxonomy descriptors*

Category	Description	Sub-scales and comments
Function	Describes what it does.	Functional interdependencies vital.
Location	Physical/geographic information.	Existing labelling scheme preferred.
Organization	Member or role for whom the information is intended.	Has a number of uses within decision making. Can be built around department structure.
Significance	Importance.	Sub-scales of Timeliness, Redundancy and Hazard.
Information Hierarchy	Linking and organization of information.	Implementation dependant.

The possible realization of the category headings was examined during the study and introductory examples of HMI were introduced for consideration. These ranged from textual descriptions through to graphical representations based on the taxonomy (charts, graphs etc.). The example shown in (FIG.9) shows a graphical representation of the Redundancy sub-scale in the Significance category. For each service an arrow indicates demand (what you want) and a horizontal bar to indicate availability (what you have)

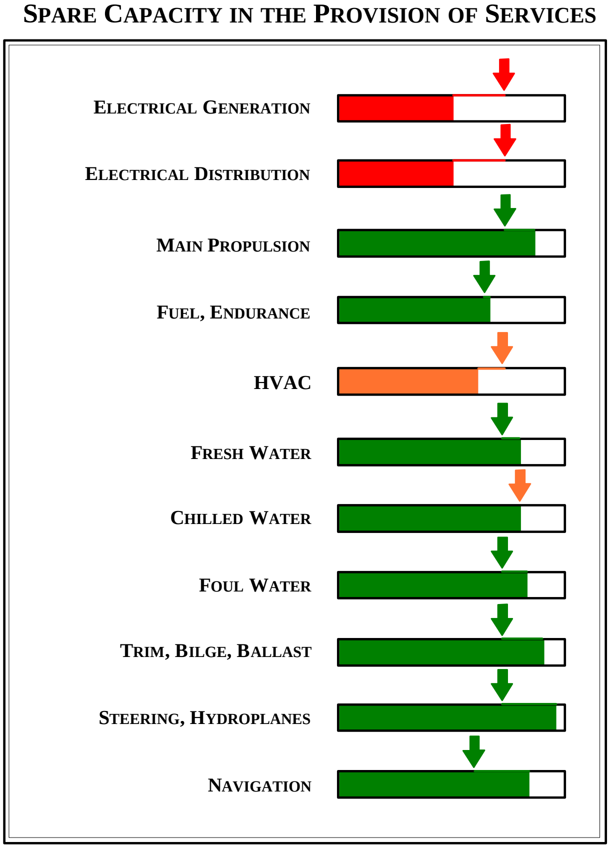

FIG.9 – REDUNDANCY SUB-SCALE

As previously discussed the RN is unlikely to change to this radically different form or concept of control in the short or medium term future (5 to 15 years) and so further investigations have been put on hold. Instead we are progressing with more immediate problems!

The Future

One of the major developments of the Type 45 AAW Destroyer operational spaces has been the combining of the Weapons Section Base with the Ship Control Centre. This has formed a single engineering management facility and should enable greater co-ordination when responding to incidents. A second facility that should improve performance in the weapon management area is the provision of PMS with HMI pages designed specifically to support those users and, perhaps as importantly, Command.

This link to Command, via the Command Advisor (CA), is the area that, because it has never existed in an electronic form before, has received most attention and has been asked the most searching questions as to what is required of it.

Many systems that are transforming mediums suffer from attachment to legacy hardware. DSAC software is an example of this as many of the current electronic systems merely mimic the functionality of the old chinagraph board solution and do not realize the capabilities of the new technology.

In transferring the weapons section base functionality to the PMS the Type 45 group has tried to avoid this and more fully exploit PMS technology. Subject Matter Experts from FOST and *Phoenix* were consulted and the key user requirements were identified. Of these the requirement to base the flow of information to Command on 'Capability' was seen as the greatest priority and having the most impact on interface design.

Capability based HMI

Given the greater physical integration of those supplying the services (the Marine Engineering (ME) Department) and those using them (the Weapon Engineering Department) the logical next step would be to integrate the information they are all using. Use of validated information in an 'enter once – use many' environment should result in a more effective and efficient platform. This could not wholly be done by the software systems onboard Type 45 AAW due to architecture constraints. However with appropriate, but minimized, use of Human to Human interaction the WE interface could supply the necessary functionality.

The Weapon Management (WM) Centre part of the SCC will only be fully manned during action but it is at this time that the ability to filter information from all the data that is received is crucial.

This filtering is accomplished by highly experienced WM personnel who provide an assessment upon which Command decisions can be made. The reporting and presentation of equipment defects is placed in the context of a capability based assessment of the remaining available functionality as opposed to a concentration on individual equipment defects.

The WM capability rides on PMS architecture to facilitate electronic manipulation of equipment and sensor status reports and capability group assessments. The flow of information within and between WM screens ensures that data relating to an equipment defect or capability is entered once and 'pushed' or 'pulled' to other users as required. Each capability group impact is assessed as to its priority within that group. The importance of the capability will obviously depend on the ship/battle scenario. In this way the WM staff produce an overview of the weapon capability and a prioritization of repair activities needed to maintain or restore capability in accordance with the Command Aim. This information feeds directly into the Command brief.

The use of a common picture and access to the same PMS information means that both the WE and ME elements of the Battle Damage Repair Organization (BDRO) can provide a coherent approach to achieve the Command Aim.

Next Steps

Currently the Machinery Control and Surveillance and Electrical Power Management elements of the PMS do not have the facility within their HMI to filter the incoming ME information into capabilities that directly support the Command brief. The PMS enables the users to interpret the information in terms of capability and the impact on Command Aim but this has to be passed verbally to the Command Advisor for onward briefing. This could be more easily, and directly, accomplished if the current PMS HMI's were enhanced to give the same facility as the WM software.

In the short term, Type 45 Batch 2 and CVF, it is envisaged that the development of capability affected/impacted dialogues will be embedded in all PMS HMI software.

In the longer term PMS will move from a facility that 'enables' management of the plant by the ship's crew to one that actually manages the platform. The role of the crew will then change to overall supervision with increased responsibility but reduced (traditional) workload.

The PMS itself will be fully integrated with the Combat system, Navigation and Steering and the Command and Control of the platform. It will become part of a greater 'information management system' that will encompass all the ship's data and may well extend to other units dependant on the role of the platform.

In all of this development the greatest challenges will be to maintain the 'man' in management as the focus of the designs and to ensure that everyone appreciates the extent to which the term 'warfighter' applies.

Conclusion

This article has introduced the work that the Marine Electrical Systems IPT has carried out in the development of task based PMS HMI's. It has shown that development from a known baseline into a future based on changing concepts of operation is possible using well thought out tools and HF methodology. It has also developed the concept that the warfighter is a very wide term and, in fact, covers each and every member of a warship's crew as each has a part to play in maintaining capability.

Acknowledgements

The authors wish to acknowledge the work carried out by the many and varied companies for and with the Marine Electrical Systems IPT, the results of which enabled the knowledge that this article has drawn upon. They include, in alphabetical order:

BAE SYSTEMS, BMT DEFENCE SERVICES, EDS DEFENCE, LIVEWARE,
NORTHROP GRUMMAN SPERRY MARINE, QinetiQ,
SIGNAL COMPUTING, SMITH.