Engine Control Rooms - Human Factors

# Summary - Onboard Field Studies

# Engine Control Room Human Factors – Field Studies


**Eric Wagner – MSI Design**
**Monica Lundh – Chalmers**
**Peter Grundevik – SSPA Sweden**


**Project Partners**

SSPA Sweden
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Kalmar Maritime Academy
MSI Design
World Maritime University


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# Short Form Summary


A research project addressing Human Factors (HF) issues in the Engine Control Room (ECR) has been carried out including on board survey of seven different ship types within the Swedish merchant marine fleet. These ships represent different ages ranging between 30 years to 6 months old. Extensive interviews with engineering crew and detailed observations and measurements of the engine and engine control rooms were included in the study. The project team consisted of SSPA Sweden, Chalmers Shipping and Marine Technology and MSI Design. Five Swedish ship owners; Broströms, Sjöfartsverket Rederi, Stena Line, Transatlantic and Wallenius Marine have participated in the project facilitating studies on vessels representing different shipping conditions.

Below is a short summary of field studies content and conclusions:

- Field measurements of physical work environment factors. The quantities measured are: Lighting, Noise, Temperature, Humidity, CO2, Dust, Vibration and Electromagnetic fields. Due to caution an recommendation is to place the control pulpit at a distance to the switch boards to reduce the stay in the proportionately higher electromagnetic field generated by the boards. It is even better to place the switch boards outside the ECR, which may also be motivated of other reasons.

- In the field study observations, some different functionalities have been highlighted. These include: The layout of the ECR, switchboards, accessibility, console design, alarm management, monitoring outside the ECR, communication, administrative area and briefing/rest area. Some conclusions are:

- Administrative duties have successively increased

- The complexity of the control systems has increased but not the transparency

- The design of ECR does not adequately correspond to the role of the modern day engineers and their duties. Functions in question are administrative, emergency and not least social ones

- Recognised knowledge about HF design and lay-out is not utilized

- Established guide-lines, rules and regulations are not consequently used

- Technical solutions may be quite acceptable but problems emerge as it becomes an integrated part of the rest of the technology. An overall comprehensive attitude towards the design of an ECR is necessary

- The change towards more software controlled systems increases vulnerability and operational risks

- How the tasks in the ECR are performed needs to be taken into consideration

- The different functions and their interaction in the ECR need to be defined

- Future rules and regulations need to take these issues into consideration

# 1 Introduction

The report starts with a general description of the different ships together with a crew demographic of the number of crew members and their nationality. This is followed by a brief description of the different types of engine control room visited. From chapter three and onward every chapter starts with a table able containing statements pinpointing different characteristics. These are assessed as fulfilled (Y) or not (N) for all ships.This assessment is based on the added impression of interviews, observations, questionnaire and measurements performed on board. This is of course not a definite truth as this is a subjective judgment, none the less we felt it important to point out the different diversities between each ship. Each statement is further elaborated under each headline respectively.

This study is based upon seven field studies on board ships in the Swedish merchant navy and interviews with engineering crews, including both officers and ratings and also differing nationalities. The visited ships represented an age span from 32 years to less than 1 year old. The selection of vessels was based upon providing a mix of different areas of activities providing a good cross sectional representation of contemporary Swedish merchant marine branches. Two of these vessels (1 and 5) are expected to continue in service with an extended service duration ranging between 10 – 20 years. As a result they are subject to control system refitting with newer technology.

Table 1 General information about the ships visited during the field studies arranged according to age from the oldest to the newest.

| **Type Of Ship** | Ice breaker | Passenger ferry | Container ship | Car carrier | Tanker | Supply ship | Ro/Ro ship |
|---|---|---|---|---|---|---|---|
| Delivered | 1977 | 1983 | 1984 | 1985 | 1999 | 2000 | 2007 |
| Built | Wärtsilä Shipyard | Chantiers de France<br>Dunkerque | Kockums AB | Kockums AB | Factorius Vulcano | Havyard Lerkil | Aker Yards |
| Nationality | Swedish | Swedish | Swedish | Swedish | Swedish | Swedish | Swedish |
| GRT | 9500 | 15900 | 24 435 | 51 071 | 11 375 | 3 382 | 23 128 |
| ME no | 5 | 4 | 1 | 1 | 1 | 4 | 2 |
| ME type | Pielstick (Diesel electric) | Sulzer 12ZV40 | B&W 6L90GB | Sulzer 7RTA6813.5 | MAN B&W | MAK | MAN B&W 9L48/60B |
| kW | 16MW / 22000bhp | 25613 | 20 200 | 20 000 bhp | 6480 | 13 440 | 9000 |
| Aux Eng no | 4 | 5 | 2 | 2 | 4 | 2 | 2 |

The crew sizes varied from four to fifteen crew members. The distribution of rank and nationality is shown in Table 2. Three of the ships had an entirely Swedish crew, one ship crew comprised both Swedish and Norwegian crew members and three ships had a mixture of Swedish and Philippine crew members.

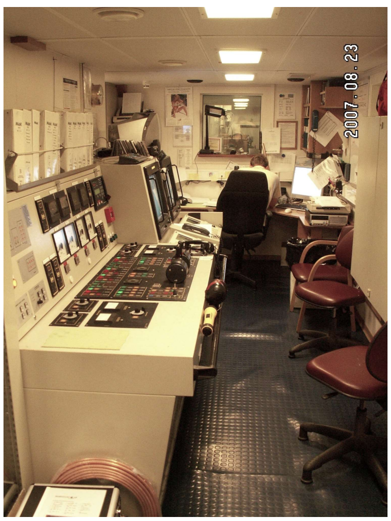
Table 2 Crew demographics *1) Swedish *2) Philippine *3) Scandinavian

| **Crewing** | S*1) | P*2) | S | P | S | P | S | P | S | P | Sc*3) | P | S | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chief Engineer | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 2:nd Engineer | 1 | | 1 | | | 1 | | 1 | 1 | | 1 | | 1 | |
| 3:rd Engineer | 2 | | 2 | | | 2 | | 2 | 1 | | | | | 1 |
| Electrical Engineer | | | 1 | | | 1 | | | | | 1 | | | |
| Electrician | | | 1 | | | | | 1 | | | | | | |
| Repairman | | | 2 | | | | | 2 | 1 | | 1 | | | |
| Motorman | 5 | | 6 | | | 2 | | 2 | 1 | | | | 1 | |
| Apprentice | | | 1 | | | | | | | | | | | |
| Total | 9 | | 15 | | 7 | | 9 | | 5 | | 4 | | 4 | |

## 1.1 Engine Control Room A

This ECR has been built by the same yard as ship D and at about the same time. The ECR instrumentation is primarily hard control with a computerized alarm handling system identical to ship 1. For the alarm system the HMI used is a function keyboard for data input. Again there are problems of integration soft control technology into the physical console design. Positively the switchboard instrumentation is facing the console making an overview easier. One feature that was noted on the switchboards is that certain instruments have been angled (power supply) to facilitate an improved viewing angle from the main console. The same feature was noted in ship D. Note again the need for work space for documentation at the console.

## 1.2 Engine Control Room B




This ECR represents a type found on a smaller special service vessel built about 2000. The ECR is built as a wrap around corridor around a central casing containing the thrusters unit. The hard control units have been reduced in number quite dramatically and most control and monitoring functions are controlled via the computer based workstations. Each work station is comprised of one 19" monitor and one function keyboard. Usually one display is always dedicated to the alarm list display and the other display allocated to process graphics. This is generally the case on all vessels visited that include computer based control and monitoring systems. The transition to computer display technology has introduced a hierarchical approach to information display and control functions. An overview of all shipboard functions is not usually possible due to a limited number of displays available. It could also be referred to as the hierarchical keyhole approach. The normal workstation in this instance is the administrative workstation located at the far end. This is generally also the case on all vessels visited. The engineer is then usually sitting with his back to the control system.

Switchboards are located in the forward compartment and thereby separated from the ECR. Note also in this instance as with all other newer vessels the disappearance of mimic panels which have now been integrated into the process graphics. The ECR also included windows facing out into the ER. The ECR did not contain any briefing, rest or pantry area.

## 1.3 Engine Control Room C

This illustration represents a newer vessel's ECR also equipped with two operator workstations. As in most cases one display is dedicated to an alarm display. Input is via a function keyboard and trackball. The ECR also contained an administrative workstation in addition to the engineering office.

Switchboards are located directly in front behind the console. What is interesting in this case is the separate engineering office with a port light. This was the only vessel visited that had a well equipped office/rest/briefing area directly connected to the ECR. The office provided also a rest area. The ECR also included a small pantry area adjacent to the administrative workstation in the ECR.

## 1.4 Engine Control Room D

This ECR (engine control room) represent a conventional hard control system from the early 80's.Instrumentation and control systems are for the most part hard wired conventional controls and information displays arranged in 3 consoles. That, which has been computerised, from an instrumentation perspective, is the alarm system, the fire detection system, the separator system and tank level monitoring systems. However pumps, tank switchovers, fans etc. remain dedicated hard wired control functions.

The consoles contain a high level of process mimics with controls and indicators interspersed at their physical positions in mimics. This may be described as a parallel presentation system as the engineers have a complete overview of all systems and their actual states under their supervision. Extensive external monitoring of other areas is provided by 7 CCTV displays arrayed above the forward and port consoles. Note that the central administrative workstation – which serves as the main workstation during operations – was installed at a later date. From this position all alarms can be monitored. The ECR contains three positions at which alarms may be monitored. These include the original hard wired cabinet with alarm display indicator lights, a secondary hard wired ALP (alarm light panel) and the computer displays at the console and at the administrative workstation. Switchboards are arrayed around three sides of the ECR. This area did not have a briefing, rest or pantry area.

## 1.5 Engine Control Room E

This vessel represents one built during the 80's. It is for the most part hard control with a computerized alarm handling system and limited process graphics displays used for monitoring only and not control functions. Process mimics are also used to a large extent. Note that the switchboards are located directly behind the console. Maintenance in this respect was difficult in regards to the console as it was butted up directly against the bulkhead. One interesting aspect in this ECR was the use of windows facing out into the ER. The main workstation (primary) is located at the far end of the ECR and the alarm system is located at the other end of the console.

## 1.6 Engine Control Room F

This ECR, also quite new, show the main control console and operator workstations. In this instance there are two separate almost redundant workstations.. In respect to fire separation, the splitting up with spatial separation between the two workstations is good. Should the port side workstation go down then these functions will not be available for the engineers. Note the transition to a few hard control separate units. Generally there remain about 30 hard control units on the console when a vessel is equipped with computerised control and monitoring systems. The installation of an almost identical workstation on the starboard side does represent some improvement in regards to system redundancy on the HMI side.

Also note the need for document handling in conjunction with the displays In this vessel, TFT flat screen displays were used which provide much clearer display images – particularly in high ambient lighting conditions. The input devices here consist of QWERTY keyboards and a combi-trackball/mouse pointing device. Switchboards are located aft of the ECR in a separate compartment. What becomes evident is the need for certain instrumentation regarding for example power consumption and supply which is located on a switchboard to be provided with repeaters on the console. The administrative workstation is located forward and to the left of the console. This ECR provided a good briefing/rest/pantry area.

## 1.7 Engine Control Room G

This ECR represents an older one visited and that has been successively refitted with computer based control and monitoring systems. It has at the time of the visit undergone a new refit with a completely new digital control system. Two workstations are providing HMI redundancy. One interesting aspect is that certain functions have been retained as hard control. The hard control functions for propulsion is located to the right of the displays. These provide control redundancy for engine control should the displays go down. This philosophy has been adopted due to the critical nature of operations. Note also here the need for documentation at the console. This again is a recurrent theme in all vessels visited.

This HMI solution utilises conventional QWERTY keyboards with mouse pointing devices. The ECR has been equipped with a an improvised administrative workstation and a rest/briefing area.

# 2 Field Measurements

Field measurements in engineering spaces have been performed on board seven ships under Swedish flag. The following physical work environment factors below have been investigated:

Lighting
Noise
Temperature
Humidity
$CO_2$
Dust
Vibration
Electromagnetic field

The measured levels for ECRs are compared to standards defining comfort zone as well as danger zones. Regarding vibration, some levels were found to be unpleasant even though they were far from high threshold limits but should require remedial measures.

For electromagnetic fields, there are no exact defined limits for dangerous exposure levels. A discussion is required including typical values for electromagnetic radiation, reference levels for general public and the caution principle.

The results from each of the eight factors are summarised in the following sections.

## 2.1 Lighting Levels

The equipment used was a Testo 545 light meter.

The following data is according to standards:

Comfort zone: 500 – 1000 lux (Note that guidelines stipulate differing lighting values dependent upon the work being carried out). The following summarises maximum and minimum levels found aboard each vessel.

Danger zone: 100 000 lux

| | Max (lux) | Min (lux) |
|---|---|---|
| Ship 1 | 600 | 25 |
| Ship 2 | 620 | 8 |
| Ship 3 | 1382 | 107 |
| Ship 4 | 880 | 27 |
| Ship 5 | 915 | 135 |
| Ship 6 | 258 | 141 |
| Ship 7 | 752 | 85 |

The lighting levels are a bit varied and can seldom be classified as perfect. Sometimes the levels are quite low forming dark areas. This is often the case behind the switchboards thus inhibiting maintenance work from the rear. The selection of proper luminaries is also an item for discussion particularly when used in conjunction with computer screens. All vessels provided sources of indirect or direct visual glare due to lighting arrangements and the selection of the overhead lighting fixtures. In some instances alarm signals could not be seen in the displays due to indirect glare sources. With the increased usage of computer displays, more effort will be required in planning the lighting and selection of proper fixtures. As a great deal of administrative work such as filling in tank levels occurs at the console, immediate task lighting possibilities should be provided.

However generally the lighting levels do not represent any major problem and they are most often good or acceptable. The areas with very low levels are generally located in seldom used areas of the ECR. In some cases it would be suitable to increase the general lighting levels. However it is easy to sense the lighting and to react if they are experienced as low. In such cases it is normally easy to take care of the problem.

In the ER the lighting levels may be very low in certain obscure areas and it is often necessary to use an electric torch. The discussion above regarding - easy to sense the lighting and to react - is applicable in the ER as well.

## 2.2 Noise Levels

The equipment used was a Testo 815 sound meter.

The following data is according to standards:
Comfort zone: 0 – 85 dBA
Danger zone: > 94 dBA

| | Max (dBA) | Min (dBA) | |
|---|---|---|---|
| Ship 1 | 73 | 69 | max 104 dBA in ER |
| Ship 2 | 69 | 68 | 89 dBA, thrusters at full power in ECR<br>max 107 dBA in ER |
| Ship 3 | 69 | 68 | 77dBA in switch board room<br>max 105 dBA near main engine in ER |
| Ship 4 | 71 | 68 | max 105 dBA near main engine in ER |
| Ship 5 | 69 | 68 | max 104 dBA near main engine in ER |
| Ship 6 | 73 | 68 | 89 dBA when door open to ECR towards the ER |
| Ship 7 | 70 | 68 | |

The noise levels are generally low and acceptable. When having the switch board in the ECR, the generator switch give momentary rise to higher noise which is avoided if they are placed in a separate room. This argument together with the ones below regarding temperatures, humidity and electromagnetic fields, point towards having a separate room including switch boards.

Another important observation is the high noise level when opening the door between the ECR and the ER. The noise level registered is well above the comfort zone. The solution to this problem can be a noise reducing vestibule between the rooms.

As in the case for lighting levels it is easy to sense the noise level and to react if they are experienced as too high. However in these cases it may not be that easy to take care of the problem. Especially this is true for the ER where very high noise levels are registered. In the ECR locks and muffle environment are measures to lower the noise levels. In cases of irritating high noise levels on air-condition fans, they will sometimes ran at lower speed or be shut off to reduce the noise.

## 2.3 Temperatures

The equipment used was a Testo 615.

The following data is according to standards:
Comfort zone: 18 – 23 °C
Non optimal zone: < 1 °C, > 37 °C

| | Max (°C) | Min (°C) | |
|---|---|---|---|
| Ship 1 | 29 | 22 | max 34 °C in ECR |
| Ship 2 | 26,6 | 21,6 | max 36 °C in ER |
| Ship 3 | 22,3 | 15,1 (in switch board room) | max 32 °C in ER |
| Ship 4 | 24,9 | 23,1 | max 29,2 °C in ER |
| Ship 5 | 25,3 | 24,6 | max 34 °C in ER |
| Ship 6 | 21,7 | 19,8 | |
| Ship 7 | 22,2 | 15,1 | |

Temperatures ranges in the ECRs examined are generally within the acceptable comfort zones. However in two instances the temperature range was experienced as chilly. Temperature variation within an ECR may vary due to the intake air temperature or fan speed. The ECR temperatures are kept low /within comfort zone limits) due to operational equipment requirements and tolerances. If there are a separate room from the ECR housing all sensitive electronics (requiring lower temperature climate control) including the switch boards, this separate room may provide conditions suitable for equipment whereas the ECR may have more comfortable temperatures all over.

In the ER of course the temperature levels may be high at specific locations such as main engines, boilers etc.

As in the case for lighting and noise levels it is easy to sense the temperature level and to react if they are experienced as high or low. However it may not be that easy to fix the problem.

Most of the measurements have been performed with external air temperatures in the range of +12 to +20 degrees, neither extremely warm nor cold. Two exceptions to this were in operating conditions of – 10 and at about 5 degrees. The temperature may rise a bit in warm periods but especially in one case it will be much colder in the ECR with the occurrence of very cold outdoor temperatures. This is also dependent upon the method of air delivery to the engine spaces provided by large sized ventilation shafts blowing in cold air. This in turn may cause fluids in machinery to freeze if not preheated.

## 2.4 Humidity Levels

The equipment used was a Testo 615

The following data is according to standards:
Comfort zone: 30 - 70 %
Non optimal zone: < 10 %, > 90 %

| | Max (%) | Min (%) | |
|---|---|---|---|
| Ship 1 | 33 | 25 | 38 – 47 % in ER |
| Ship 2 | 55 | 40 | 22 – 52 % in ER |
| Ship 3 | 29 | 21 | 34 -17 % in ER |
| Ship 4 | 28 | 25 | 29 -20 % in ER |
| Ship 5 | 22 | 19 | 28 -15 % in ER |
| Ship 6 | 37 | 33 | |
| Ship 7 | 37 | 25 | |

Humidity levels are often low although there are examples of comfortable environments. The humidity levels are often kept low due to equipment requirements. If there are a separate room from the ECR housing all sensitive electronics including the switch board, this separate room may have conditions suitable for equipment whereas the conditions in the ECR can be made suitable for people. The humidity levels follow the outdoor climate (temperature and humidity) and most of the measurements were done during the colder and low humidity part of the year. Another factor that influences the humidity level is the used air exchange speed. Today there is no damper equipment in the ECR so there are no real possibilities to regulate the humidity.

As in the case for lighting, noise and temperature levels it is possible for a human to sense high or low levels of humidity and hence to react. To control the humidity in the ECR it would be necessary to install a damper system.

## 2.5 $CO_2$ Levels

The equipment used was Testo 535.

The following data is according to standards:
Comfort zone: 0 – 1700 ppm
AFS limit: 5000 ppm, short time exposure 18 000 ppm
Danger zone: 40 000 ppm

| | Max (ppm) | Min (ppm) | |
|---|---|---|---|
| Ship 1 | | | No measurements taken, equipment not available |
| Ship 2 | 852 | 584 | 388 – 450 ppm in ER |
| Ship 3 | 918 | 520 | 841 – 355 ppm in ER |
| Ship 4 | 782 | 605 | 542 – 389 ppm in ER |
| Ship 5 | 794 | 469 | 579 – 372 ppm in ER |
| Ship 6 | 1927 | 1746 | (fan off during measurement period) |
| Ship 7 | 875 | 600 | |

The max $CO_2$ value for ship 3 is a consequence of fans ran at half speed due to high noise at full speed. $CO_2$ levels are within acceptable tolerances with one exception. The high level case was due to fans out of function during the measurement period. The fans off give rise to higher $CO_2$ levels.

## 2.6 Dust Levels

The equipment used was a TSI DustTrak which measures the solid air pollutants. Pollutants less than 10 micrometer were selected. The concentration span for the instrument was 0-100 mg/m³.
The unit measures all air impurities (solid particles) with a size less than 10 micrometer including oil mists. In the cases of high values in the ER the dominating part is the oil mist.
The following data is according to standards:

| Ämne | År | CAS-nr | Nivågränsvärde (NGV) ppm | mg/m³ |
|---|---|---|---|---|
| #Damm, oorganiskt | 2004 | | | |
| – inhalerbart damm | | | – | 10 |
| – respirabelt damm | 1974 | | – | 5 |
| Damm och dimma, org. | 1974 | | – | 5 |
| – totaldamm | | | | |
| Damm, bomull (råbomull) | 1974 | | – | |
| – totaldamm | | | – | 0,5 |
| Damm, grafit | 2000 | | | |
| – totaldamm | | | – | 5 |
| Damm, härdplast | 1978 | | | |
| – totaldamm | | | – | 3 |
| Damm, kol inkl. kimrök | 1978 | | | |
| – totaldamm | | | – | 3 |
| Damm, mjöl | 2000 | | | |
| –inhalerbart damm | | | – | 3 |
| Damm, papper | 1993 | | | |
| – totaldamm | | | – | 2 |
| Damm, PVC | 1996 | 9002-86-2 | | |
| – totaldamm | | | – | 1 |
| – respirabelt damm | | | – | 0,5 |
| Damm, textil | 1993 | | | |
| – totaldamm | | | – | 1 |
| #Damm, trä | 2004 | | | |
| – inhalerbart damm | | | – | 2 |

The AFS limits for dust levels are between 0,5 mg/m³ to 10 mg/m³ depending on dust type.
.

| | Max (mg/m³) | Min (mg/m³) | |
|---|---|---|---|
| Ship 1 | | | No test equipment available |
| Ship 2 | | | No test equipment available |
| Ship 3 | 0,030 (fans off) | 0,003 (fans on) | max 0,632 mg/m³ in ER |
| Ship 4 | 0,004 | 0,004 | max 0,261 mg/m³ in ER |
| Ship 5 | 0,016 | 0,014 | max 0,099 mg/m³ in ER |
| Ship 6 | 0,021 | 0,019 | |
| Ship 7 | 0,015 | 0,011 | |

Dust levels are very low in the ECRs. At special places, such as the separator room, close to start air compressors (when bleeding) and close to the exhaust gas receiver (leaks) in the ER the levels may be clearly higher. Only one measurement in the ER is in the region of the AFS limits.

## 2.7 Vibration Levels

The equipment used was CVK Health Vib.

The following data is according to standards:

Acceptable zone: < 1,15 m/s² (8 hours)

AFS limit: 0,5 m/s² (require remedy measure)
AFS limit: 1,1 m/s² (whole body vibration)
Danger zone: 11 m/s² (8 hours)

The vibration measured is the instantaneous value. The dominating vibration on the ships is in vertical (z) direction. All values listed below are for z direction (except two that have special notation).

| | max (m/s²) | min (m/s²) | |
|---|---|---|---|
| Ship 1 | | | No test accomplished |
| Ship 2 | 0,34 | 0,05 | max 1,45 m/s²in ECR, only thrusters propulsion |
| Ship 3 | 0,19 | 0,06 | 0,67 m/s² switch board room, max 3,7 m/s² in ER |
| Ship 4 | 0,20 | 0,07 | max 0,75 m/s² in ER |
| Ship 5 | 0,10 | 0,05 | max 0,33 m/s² in ER during icebreaking |
| Ship 6 | 0,13 | 0,03 | |
| Ship 7 | 0,21 | 0,14 | max 1,25 m/s² under the turbine in ER 0,23 m/s² (x), 0,22 m/s² (y) in horizontal directions in ECR. The only ship with high X vibrations. |

Vibration levels were acceptable in all ECRs with the exception of two ships. One of them had quite high values when the thrusters were brought on line. In this instance the ECR is built around the azipod thrusters casing and the other thrusters is located under the switchboard room. The other vessel however did not reach these levels but vibration was present in all three directions X, Y and Z. When combined, the affect on the human body is one of discomfort. A high value 3.7 m/s² in the ER (ship 3) was found on a catwalk along the main engine. It was noted that a sign was posted indicating that 2 hour was the maximum stay permitted there. Also on a third vessel there was continual vibration during the passage reaching all the way up to the accommodation decks. The AFS (Arbetsmiljöverkets Författningssamling) limits seem to be sat high and discomfort was clearly noted at lower levels. The personal opinion of the researchers is that they found it unpleasant a bit over 0,20 m/s².

## 2.8 Electromagnetic Field Levels

The equipment used was EnviroMentor Fieldfinder

Range 0,05 µT-100 µT
Range of frequencies 30 Hz-2kHz (-3dB)
Accuracy± 10% on reading ± 0,05 µT
Triaxial X, Y and Z

In some cases the instrument reaches its limit of over 100 µT, close to some sources. Since the value 30 cm away was at highest 29 µT it is believed that there were no real cases with values very much above 100 µT.

According to Professor Maila Hietanen, Finnish Institute of Occupational Health some ordinary values of electromagnetic fields are as follows:

## Typical values of electric and magnetic fields

| Source | Distance | Electric field strength | Magnetic flux density |
|---|---|---|---|
| 400 kV power lines | 25 m from midline | 1 - 10 $kVm^{-1}$ | 8 - 40 T |
| Electrical appliances | 30 cm | 10 - 250 $Vm^{-1}$ | 0.01 - 30 T |
| Background fields at home and in offices | Ambient levels | 1 - 10 $Vm^{-1}$ | 0.01 - 1 T |
| TVs and VDUs | 30 cm | 1 - 10 $Vm^{-1}$ | up to 0.2 T |

MH, 19 May 2000, Hiroshima, Japan

FIOH

The reference levels for general public exposure to time-varying electric and magnetic fields which we have used for reference, is in accordance with the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and their guidelines for limiting exposure (ICNIRP 7/99).

The reference levels for general public exposure regarding magnetic flux density (µT) is expressed as:

$$\frac{25}{f}$$ in the frequency span f = 0,025 – 0,82 kHz

The higher the frequency the lower is the limit for exposure. If we chose the common AC voltage on the ship using 60 Hz = 0,06 kHz the limit for general public exposure of magnetic flux density will be 417 µT.

The following results were obtained in the field tests: When we refer to "medium" value we refer to a level between the medium and the maximum readings we have found onboard.

**Ship 1**
Electrical switchboards located in ECR.

| | |
|---|---|
| Max value close to switch board: | > 100 µT |
| Value 30 cm out from the unit: | 69 µT |
| Value 50 cm out from the unit: | 23 µT |

Generally there are high values by the switch boards.

There are low values by the control console. Although the switch boards are within the ECR they are far from operator control place. In contrary to other investigated ships this one has quit high values also 50 cm from the unit – max value 35 µT.

**Ship 2**
Has a special room for electric switch boards.

| | |
|---|---|
| Max value close to switch board: | 72 µT |
| Value 30 cm out from the unit: | 29 µT |
| Value 50 cm out from the unit: | 18 µT |

There are generally low values in the ECR and by the control console.

**Ship 3**
Has a special room for electric switch boards.

| | |
|---|---|
| Max value close to switch board: | 83 µT |
| Value 30 cm out from the unit: | 16 µT |

There are generally low values in the ECR and by the control console.

**Ship 4**

The electric switch boards are within the ECR.

| | |
|---|---|
| Max value close to switch board: | > 100 µT |
| Value 30 cm out from the unit: | 19 µT |
| Value 50 cm out from the unit: | 14 µT |

Generally there are medium values by the switch boards.
There are low values by the control console.

**Ship 5**
The electric switch boards are within the ECR.
Several high values by the switch boards.
Two high values also at 30 cm.

Generally there are medium values by the switch boards.
There are low values by the control console.

**Ship 6**
The electric switch boards are within the ECR and there is a narrow passage between boards and console.
Max value backside switch board: 83 µT
Generally there are relatively high values in the ECR.

The values by the control console behind the back towards the switch boards are around 30 µT.
There are low values by working places in the end of the ECR.

**Ship 7**
The electric switch boards are within the ECR.
Several high values by the switch boards.
Generally there are medium values by the switch boards.
There are low values by the control console.

The measured electromagnetic fields levels were normally some few µT or less. The switch boards could give over 100 µT quite close to the cabinet or near big power cable packs. However the field dies out very fast. Since it is unknown if these fields have any impact on the humans, the caution principle is recommended. It is inconvenient and unnecessary to stay near these sources often. The control console shall therefore be placed at a suitable distance from the switch boards to reduce the fields. Ideally it is better to place the switch boards and other high voltage equipment in a separate compartment from the ECR, and send signals from the switch boards for appropriate presentation in the ECR.

## 2.9 Instruments Used

| | |
|---|---|
| Vibration | CVK Health Vib |
| Sound | Testo 815 |
| Lighting | Testo 545 |
| $CO_2$ | Testo 535 |
| Temperature/humidity | Testo 615 |
| Air flow | Testo 405 – V1 |
| Air particles (dust, oil mist) | TSI Dust Track |
| Electromagnetic fields | EnviroMentor Fieldfinder |

## 2.10 Summary

Measurements of physical work environment factors in the engineering spaces and control rooms have been performed on board seven ships under Swedish flag. Those factors that were investigated include: lighting, noise and acoustics, temperature, humidity, $CO_2$, dust and other airborne particles, vibration and electromagnetic fields. This report refers to the actual measurements found and may not address other issues concerning a given factor.

Some short notes regarding the results:

- Lighting levels are most often good with certain exceptions in specific areas.
- Noise levels are within the established norms in the Engine Control Room (ECR) when access doors are closed. To reduce high noise levels when opening a door to the Engine Room (ER) a noise reducing vestibule can sometimes be a solution. In the ER the noise levels are as expected higher within the range of 100 dBA. With the switch board located in the ECR, it give rise to higher although only occasional noise sources which can be avoided if they are placed in a separate room. Other noise sources such as ventilation fans may be more of an continual irritating factor rather than exceeding established guidelines.
- Temperatures are most often comfortable. In the ER the levels may be high adjacent to the main engines and boilers etc. which is to be expected. The temperatures in areas such as the ECR and switchboard compartments are kept low considering the equipment operational and technical requirements. If there is a separate room from the ECR which includes switch boards and other sensitive electronics, the temperatures in the ECR may be kept more comfortable for people all over.
- Humidity levels are often low. The environment is often very dry due to care of equipment. If there is a separate room from the ECR including sensitive electronics, this room may have conditions suitable for equipment whereas the conditions in the ECR can be made suitable for people.
- $CO_2$ levels are within acceptable ranges with one exception. This high level case was due to fans being turned off to get more comfortable temperature.
- Dust levels were generally very low in the ECRs. At specific places in the ECRs the levels may be of a somewhat higher medium range.
- Vibration levels were acceptable in all ECRs with the exception of two investigated ships. One of them had high values when the thrusters were brought on line (located within the ECR area), and on the main engine catwalks of another vessel. In the ERs there were examples of very high vibration. The AFS (Arbetsmiljöverkets Författningssamling) limits seem to be set high and discomfort was clearly noted at lower vibration levels.
- Electromagnetic fields levels were normally some few µT or less. The switch boards could give over 100 µT quite close to the cabinet or near big power cable packs. However the field dies out very fast.
- A cautionary approach to electromagnetic fields is recommended: and the design of ECRs etc. should make it unnecessary to continually be working immediately adjacent to sources of electromagnetic fields. Control console should be placed at a suitable distance to the switch boards. Even better of course is to place the switch boards outside the ECR and provide the ECR with the necessary slave repeater instrumentation found on the switchboards.

# 3 Engine Control Room Layout

| | Ship No: | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| **3 Engine control room shape and layout** | 3.1 ECR shape, size and general arrangement appropriate for task performance and functions | Y | N | N | N | N | N | N |
| | 3.2 Adjustment in design towards meeting the new demands which the changes in task performance implies | N | N | N | N | N | N | N |
| | 3.3. The ECR lay out and general arrangement facilitates an efficient interpersonal communication | Y | N | N | N | Y | N | Y |
| | 3.4 The design of the ECR facilitates an appropriate movement pattern within and through the ECR | N | N | Y | Y | N | N | N |
| | 3.5 Enough space to perform maintenance activities within the ECR | Y | N | Y | Y | Y | N | Y |
| | 3.6 ECR located with direct access to ER | N | Y | N | Y | N | Y | Y*1) |
| | 3.7 Spare space for future additional equipment | N | N | Y | Y | N | N | N |

*1) Noise reducing vestibule

## 3.1 ECR Shape, Size And General Arrangement Appropriate For Task Performance And Function

The shape and size of the Engine Control Room implies certain possibilities but also limitations as it somewhat determines one of the most important factors, the engineers ability to overview the relevant process and equipment states. The shape and size also has an effect on the communication within the ECR, task performance, reach envelopes, access for maintenance activities, traffic patterns, storage and other facilities. The seven ships investigated represent corridor shaped (3), rectangular (2), square (1) and u-shaped (1) control rooms. The U-shaped represents in essence a corridor wrapped around a thrusters' casing.

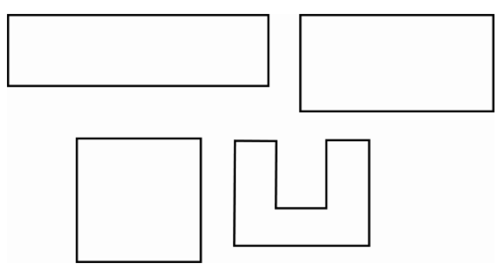


*Figure 3.1 Different shapes of the ECR*

With one exception it was not possible to get a complete overview of process values without having to move around, sometimes even entering another compartment as two of the ships had the switch board located in a separate room without vital relevant operational data being transferred to the ECR computer system. The ship which did provide a good overview, was square shaped and was equipped with traditional conventional instrumentation and equipment (see Figure 3.2). The 3: rd engineer's (watch going) work place was centrally located. A slave alarm station and a computer screen with information about the auxiliary engine are placed on the desk in front of the engineer. The controls and displays for the main and auxiliary engines together with the main alarm system is within the field of vision in front of him. The ventilation and other system instrumentation is within sight to the left of the engineer and information about fuel systems, ballast systems etc. are located to the right. The fire panel is placed behind the engineer. Simply by turning the head it is possible to get a comprehensive overview (fire panel excepted). There could be a small reservation for the readability of the instruments due to the distance – however nothing which the engineers complained about probably due to a relatively good visibility of the traditionally analogous instrumentation.

*Figure 3.2 A square shaped ECR which represented a type of ECR with good overview of process values.*

Figure 3.3 illustrates a corridor shaped ECR which fails in the respect of overview when considering the area of normal activity. Important alarms screens and among other things the status of the auxiliary engines can not be checked simultaneously by the engineer (blind zones marked with pink triangles). To be able to see these, the engineer has to move about 7 meters. This seems to be a common problem in ECRs using this design and becomes especially apparent in older ECRs where additional equipment has been added at a later stage.

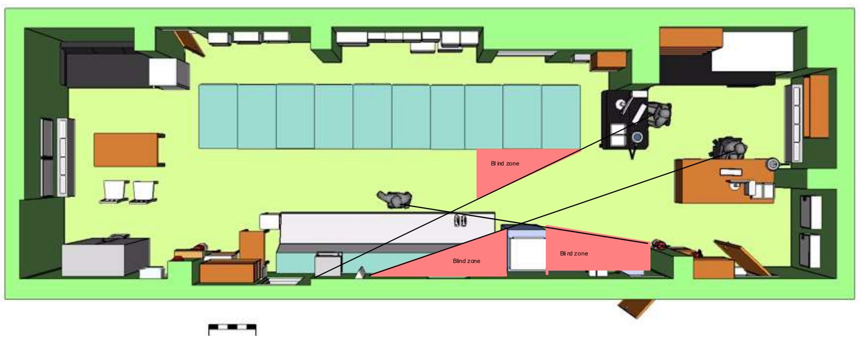



*Figure 3.3 Older ECR with multiple alarm screens and blind zones*

## 3.2 Adjustment In Design Towards Meeting The New Demands Which The Changes In Task Performance Implies

The management and operation of the engine room (ER) is of course one of the most important functions. The way in which these functions are carried out has however changed over the years as the technology on board has been developed. An evident example is of how the introduction of computers in new built ships has changed the way in which the engineers perform their tasks. The engineering log, technical manuals, planning of work etc. today involves the use of computers and an increasing amount of reference documentation such as system manuals and drawings. This had led to that more crew members are dependent upon the PC in order to perform their tasks. New tasks have also been added for instance an increase in different administrative duties such as work orders, spare parts orders, tank level records and daily reports to the shipping companies.

During the study it was possible to identify different “functions” which include specific tasks to be performed in the ECR and which are connected to different work zone areas in the ECR. No matter if the ship is equipped with conventional instrumentation or equipped with computer based systems, these following functions have to be performed.

- Normal operation of equipment
- Monitoring of system states
- Communication, external and internal
- Administrative duties such as planning and documentation
- Briefing/rest area

A task analysis of the preparation for departure performed in an older ECR with a mix of conventional instrumentation and computer monitoring and control, illustrates how the engineer has to move between different controls and instrumentation in order to prepare the engine room for departure (Figure 3.4). The link analysis is a striking evidence of the consequences of a lack of functional and logic grouping when determines the placement of instruments and breakers.

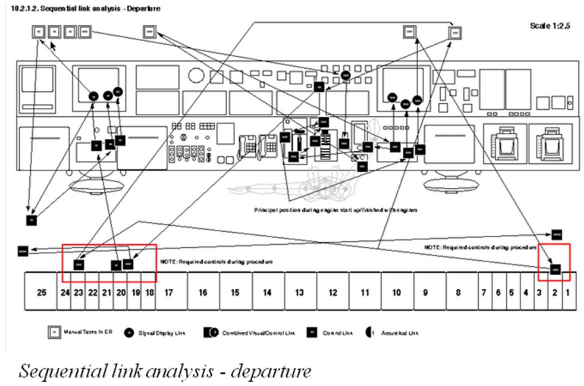



*Figure 3.4 Link analysis, departure–traditionally analogous equipped ECR*

This can then be compared to a newly built ship equipped with primarily computer based control and monitoring (Figure 3.5). The introduction of computers has implied a development of apparent work nodes and work zone areas where a number of tasks/functions are performed. Figure 3.5 shows an example of a newer ECR with evident work nodes. Node 1 is located in front of the computer used for control and monitoring and node 2 is located in front of the PC used for administrative duties.

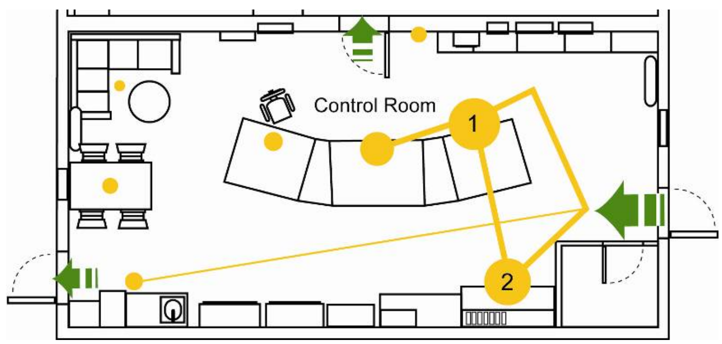



*Figure 3.5 Link analysis, departure – computer based interfaces*

Older ships which have undergone modernisation and have had computer based equipment mounted in available console space result in similar work node spatial allocation as the newer built ships have, as illustrated in Figure 3.5 and Figure 3.6.

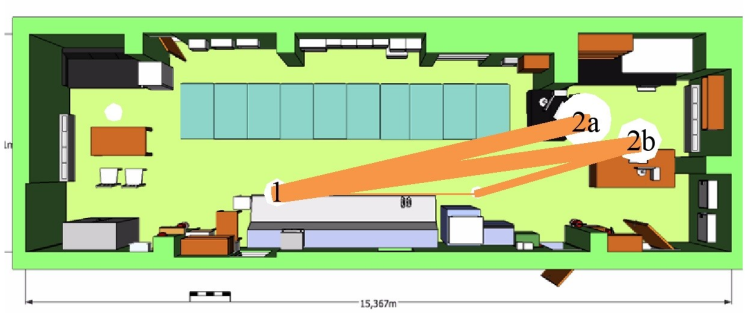



*Figure 3.6 Ship built 1985, originally equipped with conventional instrumentation and equipment but modernised with computers for primarily alarm management and limited system monitoring.*

## 3.3 The ECR Layout And General Arrangement Facilitates An Efficient Interpersonal Communication

The development of these work nodes and work zones does in some cases imply an obstruction in communication within the ECR. The communication in question is between the engineer and the equipment and between crew members. The tasks performed at the different nodes are clearly defined and refined, however in most cases also physically separated. This implies that a shift in task performance and work nodes implies an interruption of work. For instance, if the engineer in Figure 3.6 and 3.7 is working in front of the PC at node 2 a requirement to acknowledge an alarm means the engineer must rise and move over to node 1. The comparison of these two ECRs is interesting in respect to them both presenting similar problem areas, although the ships differ 22 years in age.


*Figure 3.7 Physical communication barriers between two work nodes*

If the administrative node is placed near to the computers used for control, monitoring and operation, the engineer's back is turned to one of the nodes (Figure 3.8). In the case below the ECR design does not permit an optimal overview.

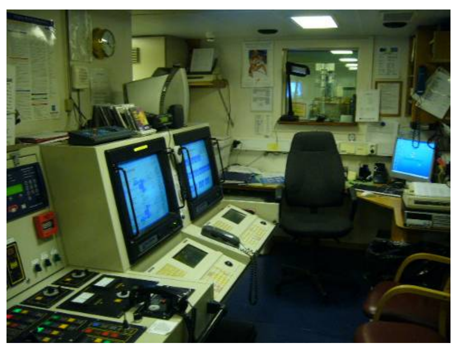


*Figure 3.8 The engineer has the back turned to either of the work nodes*

The communication between crew can also be obstructed due to distance, objects in the way and equipment facing opposite directions.

## 3.4 The Design Of The ECR Facilitates An Appropriate Movement Pattern Within And Through The ECR

The U-shaped corridor ECR represented a control room with very limited space and which of course confronts designers with a complex design challenge. Figure 3.9 shows the limited space available. Any ongoing activities will effectively block the passage area.

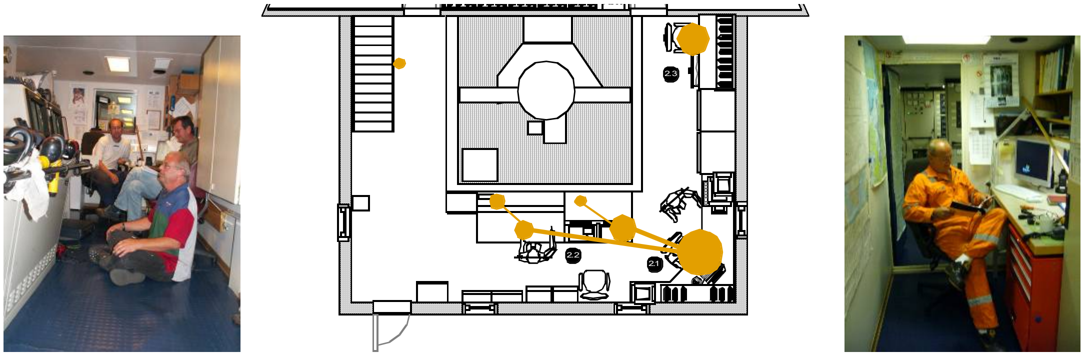


*Figure 3.9 U-shaped ECR with limited space*

Little attention seems to have been made to an analysis of how people need to movement through and in the ECR. Figure 3.10 is an example of how control panels and consoles hinder movement within the ECR. The U-shaped ECR previously discussed effectively blocked crew movement if any other activities were carried out in a given area. Yet another example was an ECR which the crew members had to pass through in order to get to their locker room and also where crew members need to pass between the console and the administrative area. A design which takes these necessary movement pattern into consideration seems in many ways be lacking. A transfer through the ECR should not disturb, distract from nor obstruct ongoing work at the different work nodes.

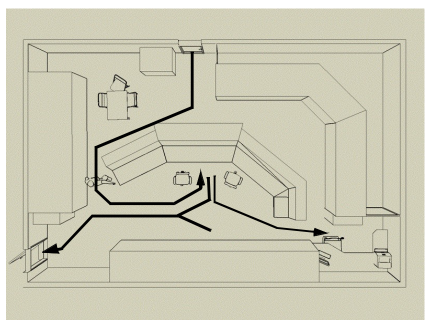


*Figure 3.10 Movement pattern within the ECR*

## 3.5 Enough space to perform maintenance activities in the ECR

Any maintenance activities which are to be performed at the console imply awkward working postures such as crawling, squatting and kneeling (Figure 3.11). If the console is not surrounded by sufficient maintenance access the task becomes very difficult.

*Figure 3.11 Repair and maintenance at the console*

On one ship the space behind the switchboard did not allow the maintenance door to be fully opened (Figure

3.12) and on two ships, access to the inside of the console was only possible from the front of the console.

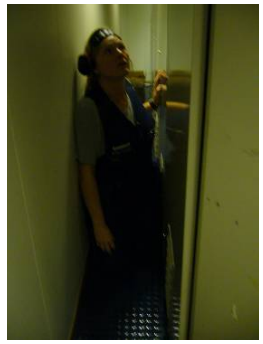


*Figure 3.12 Narrow space behind the switch board.*

## 3.6 ECR Located Adjacent To ER

Four out of seven ECRs were located directly adjacent to the ER. The clear advantage with the ECR located adjacent to the ER is the rapid accessibility. The disadvantage is the noise. When the door leads directly out into the ER the rattle of the door and the noise from the ER dramatically raises the noise level in the ECR above recommended comfort levels. This inconvenience can be reduced by a noise reducing vestibule as was the case on board one of the ships studied. Some of the ECRs in the study had very good acoustical insulation with regards to noise and vibrations. This is desirable in regards to the environmental work situation.

## 3.7 Spare Space For Future Additional Equipment

In general, the visited ships have not been prepared for the installation of additional equipment such as various computer displays. All but one of the ships (6 months old) had had technical equipment added at a later stage. The location of available space to mount the equipment varied and so also did the consequences of this. A frequently used and easy option is to mount the equipment on top of the console and create a three tier console or alternatively at various places on the bulkheads. However the angles and height of the console is not prepared for these solutions which will affect the ergonomic situation such as visibility and view over console top, when working at the console. Mounting new equipment on the bulkheads has in many examples resulted a lack of any functional grouping between associated equipment; the equipment may be difficult to reach and operate or to see from the primary work station.


*Figure 3.13 Equipment which is difficult to see or reach*

## 3.8 Summary

- The shape and size of the ECR provides the basics for design possibilities and limitations.

- The shape and size of the ECR has an impact on the possibility to overview the instrumentation and process, the communication pattern between crew members, the task performance, the maintenance activities and the traffic flow movements. The shape need to facilitate these necessary functions.

- The way the work and tasks are performed has changed. The introduction of computers as well as an increase in administrative functions has implied that new work node areas have been developed. This has not been taken into consideration when designing the ECR. The consequences are that the work nodes are separated from each other preventing an integration of tasks and work being performed and also render difficulties in the communication.

- It is essential that the engineers have relevant operational data within reach and within sight. This might include slave repeaters from instrumentation located in an adjacent compartment such as the switch board room.

# 4 Switchboards

| | Ship No: | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| **4 Switchboards** | 4.1 Located in a separate switch board room | N | Y | Y | N | N | N | N |
| | 4.2 Logical placement of instrumentation | N | N | - | N | N | N | N |
| | 4.3 Logical and consequent marking of instruments | N | N | N | Y | N | N | N |
| | 4.4Logical grouping and spacing of instruments | Y | Y | Y | Y | Y | Y | Y |
| | 4.5 Enough space to perform maintenance and repairs | Y | N | Y | Y | Y | Y | Y |
| | 4.6 Enough space to avoid electromagnetic fields | Y | Y | Y | Y | N | N | Y |
| | 4.7 Visibility of critical switchboard instruments | Y | N | N | Y | Y | Y | Y |

## 4.1 Located In A Separate Switchboard Room

The switchboard is the most dominate source generating higher electromagnetic fields. The strength of the field rapidly declines with increased distance from the switchboard. To reduce the exposure of the crew to electromagnetic fields during normal daily task performance, an evident advantage is to place the switchboard in a separate room, which was the case on board two of the visited ships. A further advantage with this set up is that the surrounding climate condition can be well adjusted to meet the requirement of the technical equipment. The disadvantage is that all relevant process values were not linked to the ECR computers or console instrumentation which forced the engineers to enter into an adjacent compartment to get these readings. This is however not any insurmountable problem as slave instruments can be mounted in the ECR once the desired process values are identified.

## 4.2 Logical Placement Of Instrumentation

The placement of the instrumentation in the ECR should follow a logical principle where functional nodes and connections between operational procedures are considered. Typical behavioural patterns need to be taken into consideration i.e. numbering from left to right and consequent equipment state (on-off).

## 4.3 Logical and consequent marking of instruments

The marking of instruments varied from metal engraved plates, plastic engraved plates, marking tape and handwritten felt-pen markings. There were also examples of controls and displays lacking identifier labels and improvised labels on the gauges. There were numerous examples of inconsistent use of colours, mirrored switches, a mixture of language (Swedish, English and Spanish) and the lack of safety covers over critical controls.

*Figure 4.1 Felt-pen marking on switch board*

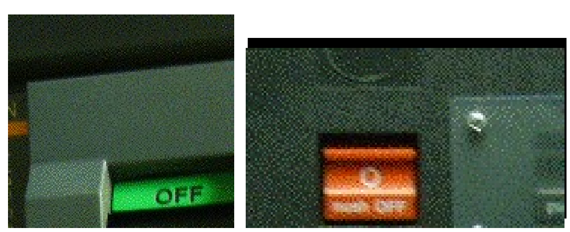



*Figure 4.2 Difference in colour coding*

Figure 4.2 shows an example of different colour coding for the same function, one uses red and the other uses green to indicate off. These switches seem to come from the same supplier.

Another example of inconsistent colour coding is shown in figure 4.3. Note the confusing use of the background colour fields in this instrument. The LED indicators read alarm and normal yet both have an orange background colour which groups them together and the orange colour indicates a warning concept.

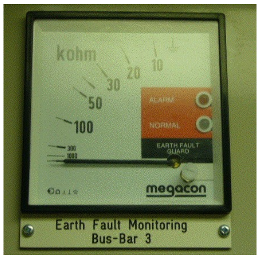



*Figure 4.3 Confusing colour coding*

*Figure 4.4 Mirrored switches*

Figure 4.4 is another example of inconsistency where switches located in the switchboards are mirrored between the right hand column and the left hand column so that on - off functions could be misinterpreted. The engineer could assume that left is off and right is on when in fact they are not. In addition when moving bulky items through the passage way an inadvertent activation of a switch could occur. This possibility was emphasized when a broken gauge glass cover was discovered along the lower portion of a switchboard.

During a review of the switchboards a number of multi dial gauges were found (multi variable displays). However there was often no associated label identifying its function (figure 2.5).

*Figure 4.5 Multi-dial gauge*

The switchboard at the far left hand side in figure 4.6 contains a number of smaller breakers. However on closer examination one of these was marked with a warning label in yellow that it shall not be touched. Such breakers should in addition be equipped with safety covers.

*Figure 4.6 Breakers lacking safety covers*

## 4.4 Logic Grouping And Spacing Of Instruments

Display and control equipment belonging to the auxiliary engines provided some examples of a logical grouping of instruments (Figure 4.7). The logic groupings within smaller units are often satisfactory. But when several smaller units are mounted together the grouping and spacing of instruments becomes less apparent. The overall overview is often lost and the information becomes cluttered.


*Figure 4.7 Logic grouping and spacing of instruments belonging to an auxiliary engine*

## 4.5 Enough space to perform maintenance and repairs

All but one ship had enough space to perform maintenance work on the switchboards. Maintenance work on the switchboard did on all ships involved uncomfortable working postures such as kneeling, squatting and bending. Insufficient space makes the maintenance work complicated and risky due to the presence of high voltage. Figure 4.8 is an example where the access doors to the switchboard could not be opened completely as the corridor width is only 40 cm. When consulting the electrician on board he described using a rubber mat to prevent him from accidentally touching leading parts as well as a mirror to see how he is adjusting a potentiometer inside the cabinet.

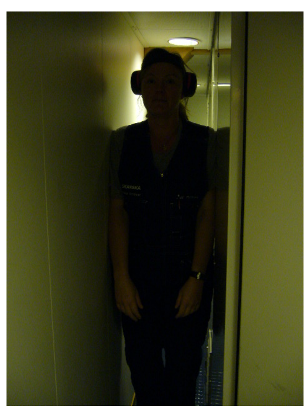


*Figure 4.8 Insufficient space behind the switch board*

## 4.6 Enough Space To Avoid Electromagnetic Fields

The strength of an electromagnetic field rapidly declines with the distance from the source. All but two ships had enough distance between the switchboard and the areas in the ECR where the crew perform the main part of their tasks. On one ship the switchboard was placed in parallel with the console and on the other ship the console was placed further away from the console but the lack of a sufficient briefing/rest area had resulted in benched being placed in front of the switchboard which was then used as a backrest. This area was used for having coffee but also as an area where information was shared among the crew.


*Figure 4.9 Switchboard placed close to the console*

## 4.7 Visibility Of Critical Switchboard Instruments

During the field studies, many of the engineers pointed out the absence of critical information in the ECR when the switch boards were placed in an adjacent compartment. Many of the operating values were displayed on the computer screens but not all of the values which were demanded of the engineers.

## 4.8 Summary

- In order to be cautious and reduce possible effects of electromagnetic fields in the ECR, the switch boards should be placed in a separate adjacent compartment.
- If the switch board is placed outside the ECR, relevant operational values need to be presented on slave panels in the ECR.
- To prevent accidents and offer suitable working conditions, the switch board must be surrounded by sufficient space to ensure adequate accessibility during maintenance activities.
- The placing of instrumentation on the switch board should be logical and follow operational procedures.
- The marking of instruments should be in consistent with regards to colours and on/off function.
- Safety covers should be used to prevent unintentional operation of safety breakers.

# 5 Consoles

| | **Ship No:** | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
|---|---|---|---|---|---|---|---|---|
| **5 Consoles** | 5.1 Console shape and size appropriate for task performance and functions | N | N | N | N | N | N | N |
| | 5.2 Allocation of instrumentation and controls on consoles according to praxis | Y | N | N | N | N | Y | Y |
| | 5.3 Compatibility of instrumentation /equipment lay-out corresponding to physical ship lay-out | Y | N | N | N | N | Y | Y |
| | 5.4 Sufficient overview of relevant instrumentation | Y | N | N | N | Y | N | Y |
| | 5.5 Suitable working postures for the task performed and equipment used | Y | N | N | N | N | N | N |
| | 5.6 Optimum reach and movement patterns for task performance | Y | N | N | N | N | N | N |
| | 5.7 Logic placing of instrumentation (both conventional and digital) | Y | Y | Y | N | Y | N | Y |
| | 5.8 Logic and consequent marking of instruments | N | N | N | N | N | N | N |
| | 5.9 Logic grouping and spacing of instruments | Y | Y | Y | Y | Y | Y | Y |
| | 5.10 Spare space for future additional equipment | N | N | Y | Y | N | N | N |
| | 5.11 Mainly conventional instrumentation | Y | N | N | N | N | Y | Y |

## 5.1 Console Shape And Size Appropriate For Task Performance And Functions

Four of the studied ships had straight consoles, two had a banana shaped console and one ship had three rectangular shaped consoles in a U-shaped formation. Although a banana-shaped console facilitates overview the consoles here were too elongated to be optimal. The Banana shaped console had a centrally placed desk which obstructs the movements of the engineer and also entails a too long reading distance (Figure 5.1).

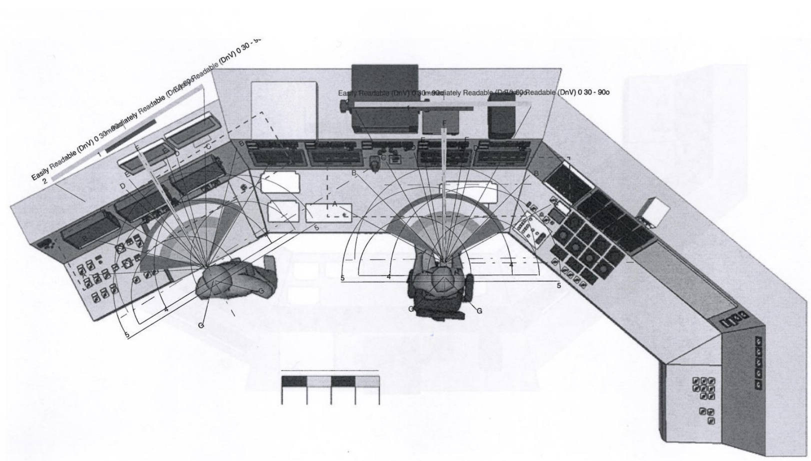


*Figure 5.1 Banana shaped console*

## 5.2 Allocation Of Instrumentation And Controls On Consoles According To Praxis

A basic rule is to place control devices on the horizontal part of the console and displays on the vertical part. A basic instrumentation design is to place the instruments according to priority (importance and frequency of use) according to a primary, secondary and tertiary field of position where the primary field is closest to the operator. The allocation of instruments should also take the working posture and fields of vision into consideration.

## 5.3 Compatibility Of Instrumentation /Equipment Lay-Out Corresponding To Physical Ship Layout

On board three of the visited ships, the compatibility of the ECRs instrumentation placement corresponded to the ship's physical lay-out, were as the other four were not compatible. . Instrumentation placement conforming to the actual physical location (starboard, port, stem, stern) of engines and units in the ER will imply less misinterpretation.

## 5.4 Sufficient Overview Of Relevant Instrumentation

It has not been possible on board any of the visited ships to get a sufficient overview of relevant instrument presentation without having to move around. Within reason, this might not necessarily present a problem. However if the design forces the engineer to illogical and cumbersome movement patterns, this can affect the work situation. Again the square shaped ECR was the best example; however readability problems forced the engineer to sometimes move to be able to see the information.

## 5.5 Suitable Working Postures For The Task Performed And Equipment Used

The introduction of computers with adherent demands on precision work has resulted in the need for a seated working posture. None of the consoles were appropriately designed for this purpose, nor are the consoles suited for a standing working posture as Figure 5.2 shows. There was not enough space for the legs or the height of the console was not optimal just to mention some of the problems. In one case it was for instance not possible to see the operating values from the seated position (Figure 5.3). Some of the engineers solved this by using a kneeling working posture in order to be able to both see relevant operational values and to write them down in the log.

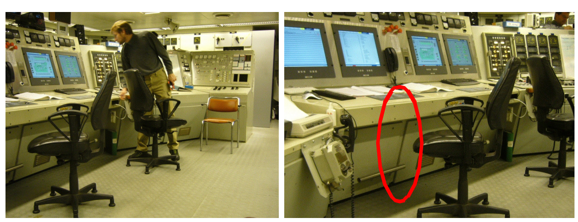


*Figure 5.2 Console not suited for sitting or standing working postures.*

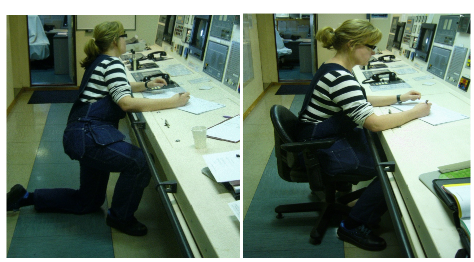


*Figure 5.3 Example of a seated working posture placed out of sight and reach from the compute screen displaying operational values and how crew members solved the problem*

## 5.6 Optimum Reach And Movement Patterns For Task Performance

One of the visited ships had an optimum placement with respect to a minimum of movements and reachability of instruments. Although the design consisted of three separate consoles, the engineer moved in a sequential pattern between these matching the operational tasks to be performed. Ships equipped with mainly computer based control system interfaces however suffered from the lack of ergonomically suitable work places.

## 5.7 Logical Placement Of Instrumentation (Both Conventional And Digital)

Five of the seven ships could present a logical placement of instrumentation. This refers to the logical placement of HMI equipment firstly in relation to the physical dispersion of the controlled equipment onboard and secondly in relation to the task performance sequences. In addition the logical placement may be dependent upon several established principals for placement including frequency of use, importance, sequence of use etc. These principals are defined by established human factors guidelines. These guidelines in a modified form are equally applicable to computerised information displays.

## 5.8 Logical And Consequent Marking Of Instruments

Established human factors guidelines define labelling and marking of controls and indicators into functional groups, sub groups within a functional grouping. Even subgroups may require a certain sub grouping. Marking refers to labelling of a control or instrument and may include textual naming or iconic symbols used to denote the function. Notably is that none of the visited ships could display a logical and consequent marking of the instruments in the ECR.

## 5.9 Logical Grouping And Spacing Of Instruments

All seven ships had a logical grouping and spacing of instruments. In creating logical groups one can use several methods of sequencing items within a group – sequence of use, frequency of use, importance, alphabetical or numerical sequential orders etc. Spatial separation is an important function in visually distinguishing between functional groups This is an important build stone in the design of the control panel as it provides the engineer with a clear operational overview of the instrumentation.

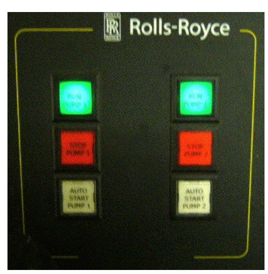



*Figure 5.4 Functional grouping and spacing*

## 5.10 Spare Space For Future Additional Equipment

On board two ships the consoles were prepared for adding and/or replacing equipment. The lack of spare space can and has resulted in equipment being placed sometimes out of reach and not close to other related equipment. A common way to place refitted equipment is on top of the console. This implied that the equipment often became difficult to reach (see figure 5.5).

*Figure 4.5 Equipment placed out of reach*

## 5.11 Mainly Conventional Instrumentation

Four of the investigated ships were mainly equipped with conventional instrumentation. One of those had only one computer screen which was designated to the alarm system. The other three had computer screens in addition to the conventional equipment. In one of them the computer system was designed for viewing only. The biggest advantage with conventional instrumentation was that this kind of equipment provides everyone in the engine crew with a comprehensive and easy accessible overview of the operational status of the various equipment of the engine room. The disadvantage with the computer based systems is that the possibility to share information is limited. This could however be solved by the use of more and large computer screens which can provide this overview.

## 5.12 Summary

- The shape of the console should facilitate the engineer having relevant instrumentation within sight and within reach. To accomplish this an U-shape form is a preferred solution.
- The placement of the instrumentation should as far as possible correspond to the actual placing of the equipment out in the engine room.
- The use of computers call for an ergonomically designed workplace at the console.
- The consoles need to be prepared for adding future instrumentation or replacement of out-of-date equipment without destroying the logic in placement, spacing or marking or obstructing the ability to have the equipment within sight and within reach.
- More and/or bigger computer screens can be used to guarantee that a comprehensive and easy accessible overview is available for all engine crew.

# 6 Digital Control Systems (Hardware)

| | Ship No: | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| 6 Digital control system (hardware) | 6.1 The data input tools (key boards, curser positioning tools) are suitable for the task and the environment | Y | Y | N | Y | N | Y | Y |
| | 6.2 The data presentation method suitable for the task to be performed | Y | Y | Y | Y | Y | Y | Y |
| | 6.3 Redundancy of system alarm, control and monitoring (failure of computerised HMI devices) | Y | Y | Y | Y | Y | Y | Y |

## 6.1 The Data Input Tools (Key Boards, Curser Positioning Tools) Are Suitable For The Task And Environment

Hard control refers to control and instrumentation systems that involve command input and information output via computer terminals comprised of keyboards – either using standard QWERTY keyboard/pointing device solutions or dedicated function keyboards, cursor positioning tools and computer screens/displays.
Of the four vessels that included digital programmable electronic systems, PES equipment control and monitoring systems, the soft control input tools and methods on two consist of simple object selection by means of a trackball and then selection of the appropriate function via the function keyboard (figure 4.1). The function keyboard consists of dedicated function keys for display call up, function execution such as start/stop, open/close etc. Soft keys (virtual keys) for display call up may also be interspersed within the graphics presentation. Cursor positioning in the display is accomplished by means of a trackball.

*Figure 6.1. An example of a function keyboard used in conjunction with what may be described as semi-graphic HMIs*

On the other two vessels using the desktop interactive approach, data input and command execution involves basically all interactive steps being performed with the mouse cursor pointing device including control functions via pop up windowing techniques (figure 6.2).

*Figure 4.2. View of a soft control workstation based upon the Windows desktop approach and mouse pointing device.*

The use of mouse pointing devices on the normally inclined horizontal console work surface may create problems in that it may wander – and the cursor with it. In one instance this happened when a binder was placed upon it activating the select function which in turn executed a non desirable control action. In this instance fixed cursor pointing devices should be used. For the function keyboards these are usually secured into the console work surface. For the QWERTY keyboards, these are left free and can be moved about on the work surface.

When regarding digitalised soft control, two distinctive approaches are being pursued by different suppliers. The one approach follows the traditional method for display management and interaction techniques represented by simple display structures and function keyboard solutions which we refer to as the semi-graphic dedicated function keyboard method. The second trend involves HMI solutions based primarily upon a Windows HMI platform including those features associated with this platform and also standard data input tools such as the QWERTY keyboard and mouse pointing device which we can refer to as the office desktop design approach.

The suppliers of the soft control systems for machinery control or in the case of hard control configurations included:

- Valmarine (1)
- Kongsberg NorControl (2)
- SAM (1)
- Praxis (1), this is a new yet interesting contender on the market
- SAAB - (alarm presentation and handling only (2)

PES HMI systems and data input/output devices consist of two forms. The traditional function keyboard and semi-graphic display approach and the Windows desktop interactive graphics approach. Of the latter all (4) were based upon variations of Windows operative system platforms. The new PES HMI solutions provide the only access point to control equipment in the ECR. Only one vessel retained hard control redundancy for control of for example diesel generator set configurations as this was considered a critical function.
Of the soft control systems, two were based upon the Windows desktop design metaphor and two were based upon dedicated function keyboard solutions. Of the systems used for passive monitoring and alarm handling all three were using dedicated function keyboard approaches.

Of the above soft HMI solutions, two of these proved interesting for different reasons. The Valmarine system proved interesting as it was equipped with a small display integrated into the function keyboard providing redundant means of accessing object information and control functions (Figure 4.1). PRAXIS also proved interesting. First it is a new player on the scene. Secondly is the ease of modifying displays onboard during operational activities. However this raises a question regarding class approval somewhat equivalent to ship’s drawings which may not be altered after commissioning. How does this rule apply to control system’s displays?

Another aspect with soft control is that it is common to integrate the control actions of several items of equipment into one linked subsequence consisting of separate items of equipment activated by one simplified command input. The question here is just how much the engineer is aware of all of these discrete subordinate automatic command sequences – and are they indicated in a proper manner. Generally HMI design guidelines for PES (programmable electronic systems) stipulate that the operator must be aware of all state changes occurring which these linked invisible subsequence functions may not provide. This contrasts with hard control whereby each individual component is represented and activated in the appropriate sequences. It is interesting to note that only two of the older vessels did have special sequence displays that display linked subsequence component activation.

## 6.2 The Data Presentation Method Suitable For the Task to Be Performed

The number of displays per workstation varied between one or two. This was also the case for those vessels using soft technology for alarm and passive system monitoring only. Of the four vessels using soft control two had one keyboard (function) dedicated to each display while the two Windows based platforms used one keyboard with seamless cursor movement between the two displays. Each workstation is comprised of two displays and one input device in the form of a QWERTY or function keyboard and a pointing device On three of the vessels fire separation between the workstations was minimal.

It was also observed that all vessels dedicated one display to the alarm presentation with one display allocated to process graphics etc. This restricts the overall overview of onboard systems.
It was noted on those vessels using CRT displays that the displayed image quality was not as sharp as the TFT displays and were also subject to obscuring information in the displays due to indirect glare from overhead lighting. It should be noted that few of the vessels had overhead lighting fixtures suitable for work with computer displays. It is also of interest to note that the new TFT displays use software driven menus for adjustment of display quality such as brightness, contrast etc. as compared with the older CRT hard controls. One of the problems here is the fact that with two displays for each workstation, one is always allocated to the alarm presentation while the second display is allocated to the graphics or mimics. It is impossible to simultaneously present several related displays that may be required in a given situation. A process overview equivalent to the older console based mimics is not feasible nor presentation facilities provided for this. Display quality varied between the vessels, but by far the best quality was provided by the TFT displays. All displays were 19”.

Another factor to be considered is that the newer high resolution displays permit finer select sensitive areas which increase the precision required in cursor positioning tasks.

## 6.3 Redundancy Of System Alarm, Control And Monitoring (Failure Of Computerised HMI Devices)

All investigated ships gave evidence of different solutions concerning redundancy. In regards to redundancy, this may be regarded from two perspectives. The first is HMI redundancy whereby the computer display and input devices are duplicated to provide control and monitoring should one workstation go down. In regards to this point, one should also be consider fire separation between workstations in the advent of a fire within the console damaging the workstation and its hardware including application software.

Redundancy may also be considered in regards to the digital control units for signal collection. Are all shipboard signals and functions funnelled to one unit or are they divided between several units providing split backup functionality. In only two ships did we see a distribution of control functions between several cabinets. It was interesting to note that not all of the cabinets were identified with proper identification labels.

One vessel was provided with system application software redundancy by being equipped with a backup server for the control system software. In this case the engineers use two keyboards for each workstation - one QWERTY and one function keyboard. First it should be mentioned that the two left hand displays run from the main server while the two right hand displays run off the backup server which effectively provides redundancy in presentation and command execution. However the function keyboard will only work off the backup server and not the operational server. This in effect eliminates system redundancy in command input. Should the backup server go down then the function keyboards are not usable. It should be noted that fire separation is less than desirable.

It should be noted that one ship that had been refitted retained hard control in addition to soft control for specific functions related to critical equipment operation in order to provide operational redundancy should the displays go down. This has happened previously. Had there been no hard control redundancy in the ECR then the consequences could have been quite serious.

It is of interest to note that one of the systems included display redundancy in the function keyboard supplied with the system in the form of a small built in display in the keyboard (see Figure 4.1). Should the main displays go down then the engineer has always recourse to these mini displays which allowed access to the various controlled objects.

In regards to system failures, one of the predominate causes, if we exclude software bugs, is due to earthing problems of connecters. This was particularly the case for vessels exposed to vibration such as by the use of thrusters for DP. This resulted in new ad hoc maintenance procedures being developed for continual proactive inspection routines to hinder such problems. In another situation when shifting main engines and phasing in the shaft generator a black out occurred. After consultation with the supplier the ship was advised to phase in the generator manually instead of relying upon the automatic phasing in due to a software bug problem.

## 6.4 Summary

- The function keyboard is preferable to the QWERTY for equipment control as this reduces the number of interactive steps required in the execution of simple repetitive commands (stop/start etc.). If QWERTY keyboards are used and certain functions for control or monitoring are allocated to the F1 – F12 function keys, then the keyboard should be provided with an overlay for these keys describing the function.

- TFT flat screens are preferable to CRT screens in regards to clarity of display image and resolution.

- For the control system Windows based applications, the use of a mouse for cursor pointing is not desirable. Generally fixed trackballs provide an equally as efficient method for cursor manipulation and have the advantage of not wandering about.

- The new programmable electronic systems do provide possibilities for physically compacting the control console to a greater extent.

- To provide redundancy, control signals should be split and distributed among several cabinets.

- A backup server should be provided for the software applications should the main server be damaged or go down or there is a need to reload the applications.

- HMI redundancy shall be provided by the use of two workstations – each with at least two display screens. Three are preferable – one for alarm display, one for overview display and one for group or detail display. All functions provided in the system should be available at both workstations.

- The two workstations should be physically separated to provide fire separation in the advent of an internal console or cabinet fire.

# 7 Computer Based Interface (Software)

| | Ship No: | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| **7 Computer based interface (software)**<br>This section refers to systems and interfaces for primaily control and monitoring of equipment only.<br>Under items 5.2 and 5.5 note that ships 1, 6 and 7 consisted of computerised alarm systems with some limited process overviews of a portion of onboard systems. | 7.1 Computer based HMI interfaces are suitable for the tasks | Y | Y | N | Y | N | Y | Y |
| | 7.2 Display interaction permits rapid display access and functional command execution | - | Y | N | Y | N | - | - |
| | 7.3 Only presentational view, no control functions | Y | N | N | N | N | Y | Y |
| | 7.4 Cluttered and inconsistent presentation | N | N | Y | N | N | N | N |
| | 7.5 Easy to overview systems under control | - | Y | N | Y | N | - | - |

## 7.1 Display Interfaces Suitable For The Tasks - Two Approaches To Soft Control HMI

Two of the four vessels utilising soft control used an Office desktop HMI based upon a standard Microsoft Windows HMI applications with the associated components such as pop up windowing techniques, menu bars, drop down and/or hierarchical menus, scroll windows, directory boxes, confirmation windows etc. Observations tended to exhibit increased time for visual search in the standard applications compared to the function keyboard solutions. It should also be noted that the QWERTY keyboard in operational control serves little purpose as the interaction is primarily point and click.

*Figure 7.1. The illustration shows a display based upon Windows look and feel. Note the display menu located to the left in the display which is used to select the desired display.*

## 7.2 Display Interaction Permits Rapid Display Access And Functional Command Execution

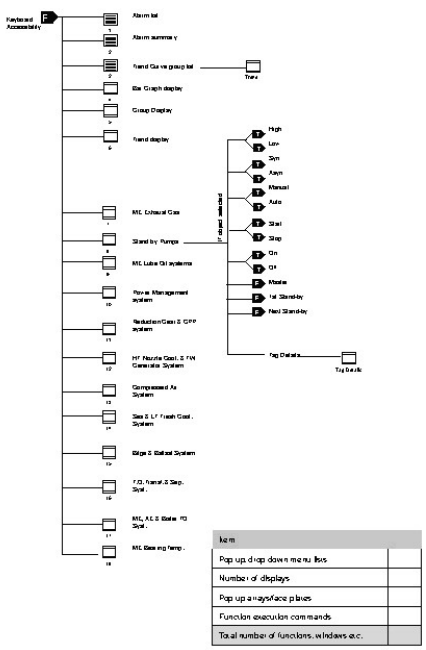
As the newer soft control systems increase in functionality such as including control system diagnostics and/or the number of objects controlled increases, the number of displays and/or pop up windowing techniques increases. This becomes obvious in comparing the two design approaches where the older soft control semi-graphic based systems generally include fewer displays.

Methods of navigation in the newer systems varied between suppliers in complexity and ease of use. By far the most complicated one included several methods dependent upon the desired function. These included expandable directory scroll boxes; drop down hierarchical menu bars etc. The simplest method for accessing a display is the dedicated display function key or soft keys arranged in a display requiring only selection and command execution.

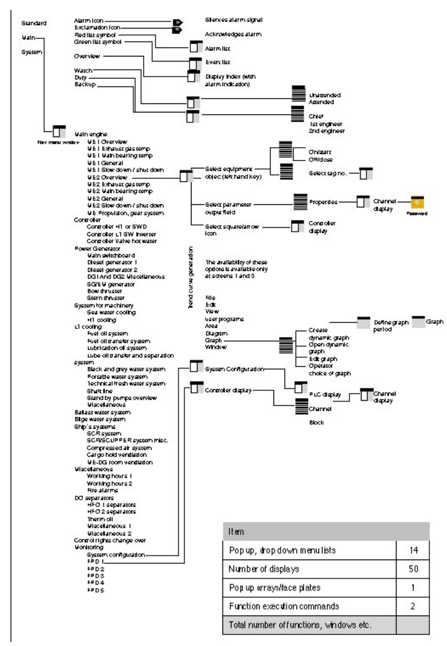
The display architecture is generally based, although with some variations, upon a long established architecture comprised of the following levels of increasing detail:

- Overview display
- Group overview display
- Group display
- Object display
- Trend display
- Alarm display
- Event display
- Running hours display
- Object configuration display (set point adjustment etc.)
- PES system diagnostics

Display architecture refers to the hierarchical structure of the displays comprising the soft control HMI system. Generally these consist of displays in breadth and depth as illustrated by the following diagrams (Figure 5.2a and b). The numbers of displays contained within the various Windows based system architectures vary between 12 displays for the larm monitoring only systems and 70 to 114 displays as compared with the semi-graphic systems 25 to 30 displays. This is just displays and not the number of pop up windows etc. that may be incorporated into the system. These also complicate the visual search and identification process.




*7.2a The illustration shows a simpler display architecture for a semi-graphic control system HMI based upon a function keyboard and trackball design.*




7.2b The illustration shows the rather more extensive system architecture for one of Windows based platforms. This system is based upon Windows drag and drop and displays are accessed via scrollable menu

For those systems equipped with function keyboards, the most often used approach is dedicated display call up keys dedicated to one specific display (Figure 7.2a) or by entering a display number followed by a confirmation function. In addition there is often the possibility, depending upon platform, to include virtual soft keys built into the display that link to a particular display often used in conjunction with a given display within the architecture. Figure 7.2b on the other hand shows a system display architecture based upon a Windows platform, a QWERTY keyboard and combi-mouse/trackball input tool. One notes that accessing displays is in this system based upon a typical Windows expandable directory scroll box. Search for a particular display now becomes more difficult due to the number of options available in the list and also the relatively small input sensitive touch areas. These may work well in an office environment but not necessarily as well in a vessel subjected to vibration and/or motion in heavy weather. As seen in figure 7.2 a and b the Windows based interfaces become much more complex in structure compared with the older “semi-graphic” display and function keyboard configurations.

In the example below the interaction involves selecting an object and then selecting the appropriate function key on the keyboard required to execute a particular state. However in one such system each object was also related to a function key as well as an object related pop up menu. However one problem here was that the same function and descriptor was used to open the menu as well as executing the highlighted function in the menu. This could lead to a human error by inadvertently performing the same key depression twice (mode and description error). The following examples illustrate the difference in using a function keyboard in command execution compared with a Windows point and click menu driven interaction method. The function keyboard requires approximately five distinct operator actions involving input. The point and click windows interaction requires approximately 7 to 9 interactive steps not including the increased requirements for visual search and orientation in the displays.

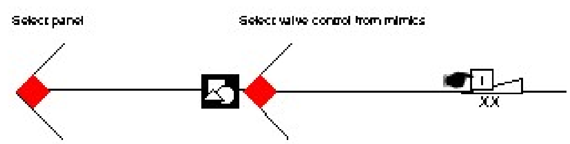



*Figure 7.3 The illustration to the above shows the number of procedural steps when inputting a command via hard control as found on three of the investigated vessels and involves basicallly 2 procedural steps.*

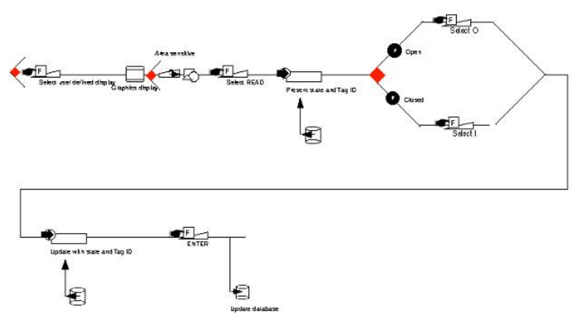



*Figure 7.4. The interaction sequence for opening a valve using the function keyboard and traditional semi-graphic display interaction method. This generally involves 4 – to 5 steps.*

With soft control the number of steps increase based upon the platform used for the HMI. In the next example one sees a significant increase in operator steps required. The following example is based upon the Window’s based office desktop HMI platform. The interaction method illustrated next involves selecting an object in the display, opening the object related menu (containing the available options) and then executing the appropriate command whereupon the window then closes. One of the issues in conjunction with software driven HMI is the use of terminology used in the commands and descriptors. At times this can become confusing or misleading.

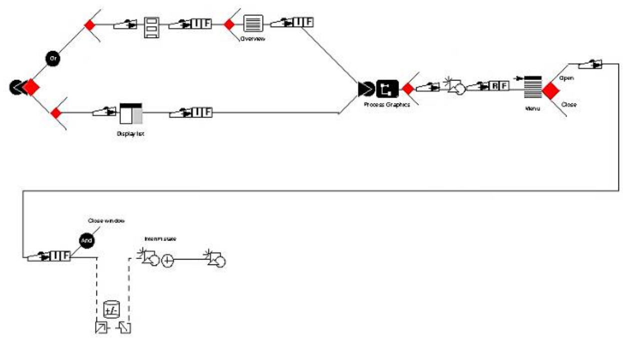



*Figure 7.5. The interaction method for opening a valve with a Windows based interaction platform. Note that in this example there are two methods of accessing the appropriate display. Note also the number of steps required – about 9 - for cursor positioning and object selection.*

Figure 7.6 shows a display access method modelled upon the Windows directory scroll box HMI component. The other methods may involve one display with all display names arranged in columns from which the user may select the desired display. The third method involves virtual soft keys embedded in the graphics display which when selected open the related display. The illustration below shows a menu bar used to access such functions as trend curve configuration etc. Generally trend configuration in this example is a time consuming process. This illustration shows the object related menu providing those available control functions for that item of equipment. Selection requires the user to draw the cursor down to the desired option. This is susceptible to inadvertent activation of an incorrect function due to jitter in the pointing device, accidentally releasing the select button on the mouse on the incorrect option. In one such menu the same text prompt (Select) not only opened the pop up menu but also executed the function in the menu. I was cautioned when examining the display architecture not to press select twice.

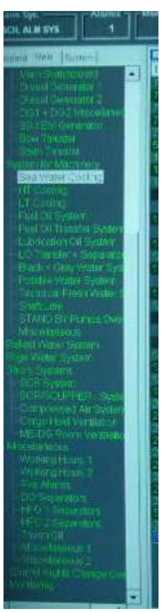


*Figure 7.6 shows the expandable directory scroll box for accessing various displays in the system.*

The investigated windows based applications often include fragmented window functions, extensive display hierarchies increasing search and identification response times. Soft control and it’s related HMI generally requires a great deal more visual search and identification as compared with traditional hard control or the use of dedicated function keyboards.

The onboard displays are usually configured by the system vendor. Most engineers mentioned the need for refinement. Only one of the systems inventoried provided basic and simple display design functions that permitted modification of the displays to more adequately reflect the onboard systems.

## 7.3 Only Presentational View, No Control

Of the seven vessels visited, three used computer based displays for alarm management and passive monitoring of a few systems onboard such as tank systems, fuel oil systems. They were not used for equipment control as such. Four of the vessels were, with the exception of stand alone applications, entirely dependent upon the soft control systems for engineering control and monitoring. This appears to be a transition solutions in between analogous and soft ware equipment.

## 7.4 Cluttered And Inconsistent Presentation

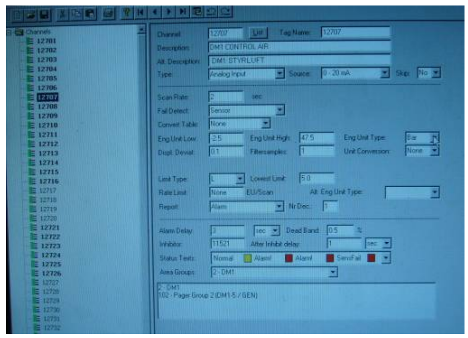


*Figure 7.7 A example of a cluttered presentation*

By clutter we refer to various display design factors such as lack of spatial separation between objects in the display, inconsistent information coding practices, number of displayed objects etc. Clutter usually interferes with visual search and object identification. Generally the number of controlled objects is not extensive in any given display. However as is usually the case with software HMI systems, information design principles to aid visual search and orientation within a display are not adopted. This is particularly the case for tabular and alarm lists or other forms of alphanumeric displays.

One can also state that visual clutter is often integrated into the display due to the software's standard components as in the above illustration (Figure 7.7) showing a controlled object's channel configuration. Although conforming to the platform's standard it does not conform to accepted graphic design principles aiding visual search and task performance.

In order to provide a clear and structured presentation the use of coding methods such as iconic, terminology, colour, shape etc needs refinement and also possible a development towards standardization. Also, the use of large screen displays facilitates a better overviews equivalent to the older mimic system.

## 7.5 Easy To Overview System Under Control

In regards to comments from engineers during the site visits none of the newer soft control systems provided an adequate overview of all important systems onboard in one display providing an overall situational awareness. This is one of the problems with only a few computer displays available and the fact that one is always allocated to the alarm display.

Due to the structure of system monitoring and control displays, an overview of equipment states is primarily based upon accessing the desired system one at a time, evaluating the status and then moving on to the next system display. Furthermore system alarm lists should admit immediate access to the related process graphic display by selecting the alarm in the alarm display.

The three older vessels employed extensive use of process/system mimics in the control consoles, and one of the vessels used specific mimics for specific critical functions such as sub sequence indicator panels. Two of the older vessels were equipped with specific sequence displays that indicated the sequence of pump start up etc. when running up the engines. This feature is particularity important with regards to linked sub-sequences that are activated by a single command.

## 7.6 Summary

- Software Troubleshooting is a major problem due to a lack of sufficient documentation and/or experience and knowledge of software systems. As the use of digital control is here to stay, there is a definite need for extended training of engineers to cope with this technology.
- In general, the functionality of Windows in most cases imply a more complex display structure which requires more operations to be performed in order to execute a task, compared to a semi graphical interface together with a functional keyboard design approach.
- As a result of the more complex structures response time in performing an operation in a critical situation will increase. The system HMI also tends to be highly fragmented in its structure, less dependent upon parallel signal recognition and more dependent upon cognitive serial information processing.
- More sophisticated point and click HMI soft control systems increase the pshycho-motoric loading when selecting or manipulating control objects which are quite small in area such as visual search for an object and/or display, identifying objects, positioning cursors on those objects, selecting the functions related to that object and executing that function.
- Small cursors and relatively small input/selectable areas on the display can be difficult to operate during harsh weather conditions and/or the vessel is subject to inordinate vibration or under conditions of operator fatigue.
- The interface should permit rapid accessibility for critical emergency functions, eliminating complicated search procedures for the appropriate configuration.
- Reviews on all vessels revealed first inconsistencies in design between displays in a given onboard control system. Secondly inconsistencies are found between stand alone system supplier solutions and the primary control system. This may range between how colour coding is used to subtle differences in symbol design.
- Console mimics provided an overview of all equipment states for all personnel (parallel presentation), the soft control HMI does not permit this today. It tends to provide a restricted keyhole view of only limited equipment or system states for one operator.
- It is of great operational help to use specific sequence displays showing the state of several items of equipment that are linked, say during main engine running up, displaying all individual items within a sub sequence and their states.
- System display architectures should be relatively shallow in depth – not more than three levels.
- The new HMI technical solutions do permit interesting possibilities however despite the modernity of the platforms they do not exhibit any tendency to combine principles from old instrumentation techniques in a newer media.
- The use of coding methods such as iconic, terminology, colour, shape etc. needs refinement regarding standardization.
- The use of large screen displays should be explored to provide better parallel overviews equivalent to the old mimic systems.

# 8 Conventional instrumentation

| | Ship No: | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| **8 Conventional instrumentation** | 8.1 Logic placing of instrumentation and controls | Y | N | Y | N | Y | N | - |
| | 8.2 Logic and consequent marking of instruments and controls | N | N | N | N | - | N | - |
| | 8.3 Logic grouping of instruments and controls | Y | Y | Y | N | N | N | - |
| | 8.4 Consistent state indication for indicators | N | N | N | N | - | - | - |

## 8.1 Logical Placement of Instrumentation

As far as panel mimics on the older vessels are concerned the layout of instruments and controls was arranged according to their position within the piping system. Few problems were found here. As far as other conventional HMI components (standardized off the shelf units) are concerned they were generally located in firstly positions reflecting the physical arrangement of the vessel and then as functional groups. One problem is the introduction of new equipment – either of a conventional or soft control nature where they are often located where there is space. This has resulted in some awkward arrangements in regards to task performance sequences and instrument visibility from normal working positions.

In some instances in regards to the switchboards for example, in order to squeeze in components into the switchboard panels on some vessels, the control devices were rotated 90 degrees. This exposed the breaker switches to the risk of unintentional activation or deactivation if manhandling large objects through the passageways. Otherwise the switchboard instrumentation is functionally allocated per cabinet and function.

## 8.2 Logical and Consequent Marking Of Instruments

For the most part all instruments and controls are arranged under a functional group label with individual component tags identifying each component. Few analogue indicators (gauges) were provided with markings indicating alarm limits. Generally these are improvised with coloured tape strips placed at the appropriate location on a gauge. The quality of control and instrument labelling is generally quite varied.
It should be noted that on one vessel the instruments were labelled in Spanish. It should also be noted that both in the soft control and hard control systems, there are numbering sequences for example for motors or cylinders that do not conform to stereotypical behavioural perception and could lead to description error.
In regards to the use of colour coding for controls such as reset function, Off/On, Stop/Start there were observed a number of inconsistencies aboard all vessels. Again this is dependent upon different components coming from different suppliers.

## 8.3 Logical Grouping Instruments and Controls

Although larger functional groupings appeared to present no major problems, one can discern sub groupings within a functional group that may not be clearly demarcated with spatial separation or other methods. Most panels include spatial separation and/or contour framing of sub groups. However there also appeared instances of misleading sequential ordering of components within a functional group or sub grouping.

## 8.4 Consistent State Indication for Indicators

The site visits indicated variation for state indication between vessels and even within the same vessel. For conventional instrumentation two forms of state indication may be considered – the analogue display showing increase or decrease in a variable and the binary indicator light indicating an equipment or machinery state such as stand by, off/on, stopped/started. The switchboards generally contain a large proportion of the analogue displays and fewer binary state indicators as compared with the consoles. The consoles tend to have a predominance of binary state indication with a lesser degree of analogue instrumentation. The newer hard control off the shelf components comprised of separate units for the most part are based entirely on binary push button devices both for command execution and state indication. The use of rotary switches, toggle switches or other multidimensional coded controls has basically disappeared from the ECR with some few exceptions were continuous output/input control is required.

*Figure 8.1. Hard control standard units or separate units that may be considered as functionally grouped layouts comprised of primarily binary state indication providing feedback about executed commands.*

One problem found in the separate units as illustrated above is that binary push buttons with back lighting for items such as pumps, fans etc are difficult to distinguish from purely indicating lights which have the same shape. There is also inconsistency in the use of colour coding for state indication between the switchboards and the console instrumentation. This is due to individual component supplier preferences and different standards as used in the electrical industry and the maritime industry.

Only one vessel used the management by exception principle for signal perception. That is indicators only indicate (back lit) if something is wrong. If everything is all right then no signal is indicated. One older vessel was equipped with conventional rotary switches that indicated by means of a blinking light if they were in the incorrect position. The main advantage of this principle is its clarity. The basic thoughts in this design are worth enabling in future development of operational systems.

## 8.5 Summary

- The use of conventional hard control still exists in primarily soft control ECRs although to a lesser extent. It is still however the predominate form on switchboards.
- In newer vessels console hard control instrumentation is mostly preassembled units provided by different suppliers as final products. This does create a number of problems in consistency of design in regards to the use of state indication coding, colour coding of functions, labelling of functions be means of icons or texts, terminology etc.
- Although there is a standard governing the differentiation in shape between binary push buttons and indicators, no supplier appears to follow this.
- Detailed examination of controls and indicators revealed differences in design and coding methods on the same vessel and between different vessels.
- With the transition to pushbuttons one decreases the multidimensional coding factors that aid visual search and identification.

- The development of the integrated control and indicator units neglects design guidelines stating that controls shall be positioned on the console horizontal surface and all displays shall be located on the console vertical surface. Visibility of alarm and state indicators tend to decrease with a placement on the horizontal surface when viewed from a distance and seated working posture.

- All indicator lamps should be standardised so that one does not need to keep an extensive stock of different lamps onboard.

# 9 Alarm systems

| | Ship No: | 1 | 2 | 3 | 4 | 5 | 6 | P7 |
|---|---|---|---|---|---|---|---|---|
| **9 Alarm** system | 9.1 Continual overview of the alarm status | Y | N | N | N | N | N | N |
| | 9.2 Consistent and clear alarm indication | N | N | N | N | N | N | N |
| | 9.3 Ancillary sub systems – not consistent with main alarm system | N | N | N | N | N | N | N |
| | 9.4 Rapid access to alarms | Y | Y | N | N | N | Y | Y |
| | 9.5 Sufficient alarm system redundancy | Y | N | Y | Y | N | N | N |

## 9.1 Continual Overview of The Alarm Status

All vessels had continual overview of alarm states but only for signals funnelled into the alarm system. All alarm points in the system, it was found, were not necessarily directed through the displays. One vessel had three alarm management levels. She had been refitted with a digital alarm management system but retained two levels of older hard wired alarm indication. Otherwise for all vessels the primary source of alarm information is the alarm display.

The alarm management and handling for engineering alarms is in principle similar on all ships with variations dependent upon the system supplier's alarm management solution. The primary display is based upon one dedicated computer screen presentation of alarm lists arranged in chronological order with the latest alarm at the top of the list. Figure 7.1 shows an older form of alarm list display from about the middle of the 80's and figure 7.1 shows another example of an alarm list that comes from a contemporary system based upon a Windows platform. The Windows based systems are not usually delivered with a function key legend for the F1 – 12 function keys, which is where the alarm acknowledge function key is usually found, unless a virtual soft key is located in the display.


*Figure 9.1 Consistent and clear alarm indication (Older)*

*Figure 9.2 Clear alarm list based on Windows*

## 9.2 Consistent and Clear Alarm Indication

The engine alarm's acoustic signals were often difficult to distinguish from other acoustical signals such as the telephone alert. This means that the engine crew has to rely on a visual signal indicator to differentiate between them.

All the investigated alarm systems displayed the alarms in list form. For the 4 newer systems there was also indication of an active alarm in the process graphic displays, usually as a text line at the bottom of the display and in some cases some form of dynamic indicators adjacent to the object in the display. The quality of alarm signals in the graphic displays varied between systems. Not all the soft control systems had direct mimic display call up from the alarm list. This you had to access separately by remembering which display the object is in.

The presentation of alarms could in some cases be ambiguous as seen in picture 9.3. There are a series of indicators labelled ALARM. If there is no active alarm then there should not be anything displayed. Some confusion arises as t whether or not there is an alarm state.

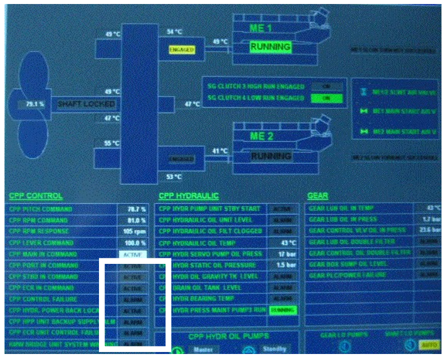


*Figure 9.3 Ambiguous alarm presentations*

One of the major problems cited by engineers in regards to alarm management systems is that one cannot see what the initial fault is and what subsequent faults that have been initiated by it are. All alarms come up as they happen. A search for a possible initiating event involves going through the list and making a qualified judgement. In the case of blackouts were all systems fail, the main task is to acknowledge all alarms as fast as possible. This usually means one engineer does nothing more than acknowledge the generated alarms while the other engineer attempts to diagnose the initiating event.

## 9.3 Ancillary Sub Systems – Not Consistent With Main Alarm System

In addition to the alarms presented in digital form in the computer screens, consoles usually include a number of units containing their own subsystem specific alarms which may or may not be funnelled to the main alarm management system. These additional alarms may be presented in separate displays or as back lit indicator lights arranged throughout the console. Should these decentralized signals not be funnelled through the central alarm management then this entails that they should be easily visible from the main working position. Illustration 9.4 illustrates a console and the location of various alarms indicating devices spread throughout the console. The primary alarm display is located at item 2. There are several other alarm points over the console and there are almost no consistencies between the different alarm presentations.

The alarms could be distributed over the console or placed beside it, on the bulk heads etc. Sometimes they were slightly hidden which contributed to the lack of overview

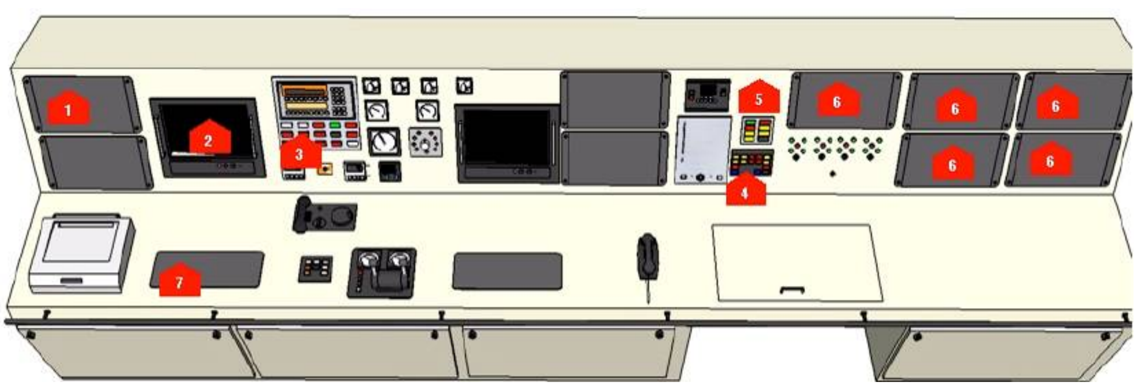



*Figure 9.4 Control system alarms consist of the centralized alarm display for machinery alarms. Alarms are also provided throughout the console as part of the various COTS units.*

All of the visited ships had additional alarms which were not consistent with the primary alarm system in presentation or coding.

The following illustration (9.5) shows an example of the location throughout the ECR of various cabinets and panels were alarm information is also displayed. These points are indicated by the red dots. This is quite representative of the older vessels that have successively had modification done to them during the years.

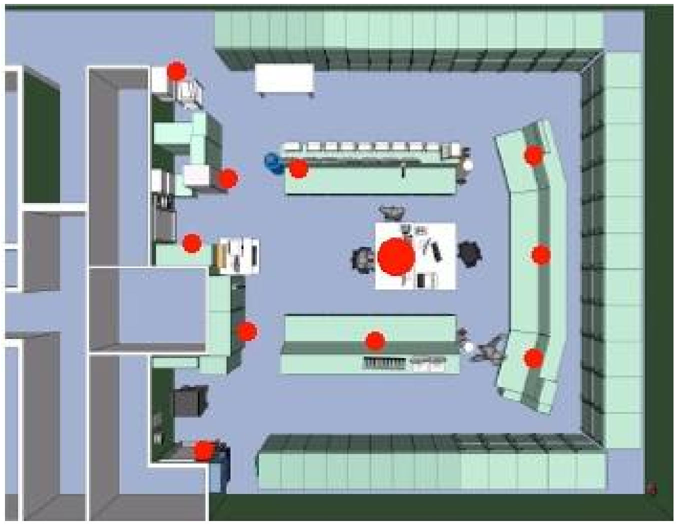


*Figure 9.5 View of an ECR with several alarm indicating points located at various positions.*

In this case the older fire detection panel (hard wired) was better than the newer computer based display for providing an overview due to the inadequate navigation between displays.

## 9.4 Rapid Access to Alarms

Alarms that are generated by the system can usually only be acknowledged from the ECR. A generated alarm may also require several corrective actions out in the engine room spaces. If the engineers are out in the engine room spaces then they must drop what they are doing and go up to the ECR to quiet the acoustical alarm. It would be advantageous to possibly have slave alarm panels such as the cabin panels at strategic locations in the engine room spaces. Only one of the seven vessels had distributed alarm panels out in the engine room spaces permitting engineers to acknowledge an alarm and observe what the alarm was. Basically what was done was to place cabin alarm panels out in the ER.

Not all systems provided a function to access the appropriate process graphics from the alarm display list option. This should be possible by means of a simple function. In most cases the display could not be accessed by this method.

In one case, the alarm system which required acknowledgement prior to executing a main engine slowdown override was located so far away that the time allowed to execute the override function was too little due to the physical movement involved. However this is a result of retrofitting newer auto shutdown monitoring equipment in an inappropriate location.

In another instance the engineer in attempting to solve a problem with the boilers, had to sit at that specific panel to make adjustments and at the same time repeatedly acknowledge alarms located in the main display 10m away.

## 9.5 Sufficient Alarm System Redundancy

By alarm redundancy we refer to several factors which include back up servers, fire separation between

control workstations, number of control workstations and screens in the ECR, distribution of system automation cabinets. The results are based upon a composite judgement of these factors.
Not all vessels have system redundancy for alarm management. Only one vessel had a back-up server unit aboard for the application software. Only one vessel had three levels of alarm redundancy – the computerised alarm management and two levels of hard wired alarm indication at two separate locations. If the alarm system is damaged (for example a fire in the system data acquisition cabinets), and with no redundancy then the vessel has no functional alarm system. The use of two identical workstations aboard provides alarm HMI redundancy assuming acceptable fire separation between the two. Alarm redundancy should also be provided in the process mimics in the system by providing more visible object coding attributes in a clear and distinctive manner. In the vessels reviewed there were shifting variations of object coding to indicate alarms in the mimics.

## 9.6 Summary

- The presentation of the alarm status needs to be developed. Both the visual presentation as well as the acoustical alert needs a differentiation that provides the engineers with information about the seriousness of the operational status.

- Not all ancillary sub system alarms are consistent with the main alarm management system which entails a situation which is firstly difficult to overview and secondly possibly contributing to misinterpretation.

- Alarm filtering of primary initiating alarms and secondary following alarms related to the initial event as yet is still not used in any of the alarm systems reviewed. It may be advisable to develop a generic filtering module that could be easily modified for specific vessels.

- Alarm systems do not provide an adequate overview of all major systems when something occurs. Neither the alarm displays nor the process graphics provide an optimal overview method of trends in system changes approaching alarm conditions and which permit pre emptive action before a situation arises. Some analogous instrumentation clearly indicates operational and non operational zones preferably by using colour coding. This clearly indicates changes in the operational values and also clearly point out when a value is getting closer to the alarm limit.

- Alarm acoustical signals vary in signature between vessels. Separate units may include their own specific signature. Alarm signal strength should be at least 10 dBA above the ambient acoustical environment.

- Soft control systems should include clear visual presentations of important operational values and their limits. Associated trend curves need to be easily accessible within the same system.

- The printouts generated by system alarm management were never really used based upon our observations.

- In diagnosing an alarm situation one may require three displays – the alarm list, a system overview display of the affected system in its entirety and a object detail display.

- Increasing the alarm overview from console units and the indicator lights can be improved by locating all of these in one structured alarm light panel array instead of being located at different positions within the console.

- Slave alarm acknowledgment panels could be located at strategic locations in the engine space compartments eliminating the need to acknowledge an alarm from the ECR. This may be important on vessels with smaller crews.

- It is important to assure redundancy within the alarm systems.

# 10 Monitoring Outside ECR

| | Ship No: | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| **10 Monitoring outside ECR** | 10.1 Windows facing ER | N | Y | N | N | N | Y | N |
| | 10.2 Surveillance camera /-s overlooking ER – view selection | Y | Y | Y | N | Y | Y | N |
| | 10.3 Surveillance camera overlooking the funnel | Y | N | N | N | N | N | Y |
| | 10.4 Surveillance camera /-s overlooking deck – view selection | Y | Y | Y | N | N | Y | N |
| | 10.5 Electronic chart display | Y | N | N | N | Y | N | N |

## 10.1 Windows Facing ER

To reduce the need for going out in the ER every now and then, it would be suitable, if possible, to install windows facing the ER providing the possibility to have some general overview into the ER. That would for instance provide the possibility to observe smoke/exhaust fumes, fuel leakage and other abnormal situations. To really get a good overview of the ER, the widow layout is in most cases probably not realistic. There were only two of the ships investigated that had  windows between the ECR and the ER.

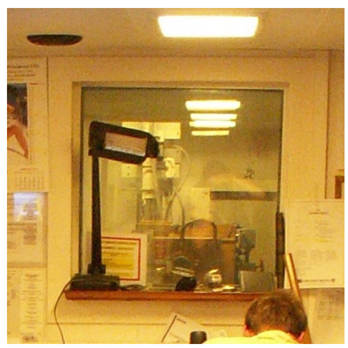


*Figure 8.1 Window facing a Auxiliary engine*

## 10.2 Surveillance Camera /-S Overlooking ER – View Selection

It is not that easy either to get the desired overview of the ER through the window. A better approach is surveillance cameras overlooking the ER. Critical sections and machineries may then be selected and several surveillance cameras may be installed. Ideally several monitors may be used for presentation in the ECR, or if there is lack of space, a view selection function can be used on the presentation screens available. One of the ships investigated had several monitors for overlooking the ER.


*Figure 8.2 Surveillance camera presentation in ECR*

## 10.3 Surveillance Camera Overlooking The Funnel

One of the ships investigated had a surveillance camera overlooking the funnel. This facility was regarded as very suitable by the engineers. The character of the smoke plume from the funnel gives the engineers useful information about the status of the engine. For instance if the smoke is very black it is a signal to check the engine.

## 10.4 Surveillance Cameras Overlooking Deck – View Selection

There are also several other places that are interesting for the engineering crew to visually monitor in order to get a better situation awareness. Surveillance cameras can be used for example to monitor essential areas of the deck, gangways, ramps and doors or specific items of equipment. The installations shall be adapted to what is especially interesting on the specific ship.

To make the best decisions, it is also important for the engineering crew to have information about the ship's surroundings. Surveillance cameras looking in the forward direction monitoring the fairway as well as aft and port/starboard are also desirable views adding relevant information. Instead of having several cameras one solution may be fewer cameras at suitable locations that can be remotely swivelled from the ECR. The survey cameras discussed here display views that are present on the bridge. One of the ships investigated had several monitors for overlooking deck, ramps, fairway etc.

## 10.5 Electronic Chart Display

Another information source that is essential on the bridge is the electronic chart display presenting the ship's position, speed and course. This displayed information is also important for the engineering crew. These examples support a wider and often necessary information transfer between the bridge and the ECR that in these cases can be accomplished without person to person communication. Two ships had electronic chart display presentations in the ECR.

## 10.6 Summary

- Possibilities to monitor the ER when working at the control console with other operational tasks represents an important enhancement of the situation awareness without the need to walk around the spaces.

- A direct way of checking the engine status is the visual view of the funnel. A camera and a screen showing this is a valuable tool.

- Cameras and presentation screens showing different essential areas of the ship and fairway gives a good situational awareness that can be helpful in decision making without the need to ask for checks and information.

- An electronic chart information presentation in the ECR will give fundamental information of ship position that is very relevant for the operational decisions. This implies fewer calls to the bridge to receive this information by voice.

# 11 Communication

| | Ship No: | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| **11 Communication** | 11.1 Sufficient internal communication | Y | Y | Y | Y | Y | Y | Y |
| | 11.2 Sufficient external communication | Y | N | Y | N | N | N | N |
| | 11.3 Internet and e-mail | Y | Y | Y | Y | Y | Y | Y |

## 11.1 Sufficient Internal Communication

All ships investigated do have internal communication functionalities. These systems for internal communication within the ship are functioning well and are very essential for the working operation onboard. The equipment consists of internal telephones, loud speakers to the bridge, emergency phones to designated stations throughout the ship and VHF. Some of the emergency phones were however not distinctly marked.

## 11.2 Sufficient External Communication

In this context we include the satellite voice communication and the cellular mobile telephone. The satellite telephone is becoming more available whereas all personnel have their own mobile telephone that is working if access to a base station network is available. Earlier the satellite telephone communication was very expensive. Although it has now become more accessible, it has not as yet become an important factor in the daily work operation. The mobile telephone may do that but it needs network contact. For personal purposes these communication systems may be very important. There were only personal mobile phones in use and no “public” job ones.

Two of the investigated ships did have satellite voice communication system available in the ECR. The other ships did not have this facility.

## 11.3 Internet And E-Mail

The access to Internet and email is mostly through a satellite channel. These facilities are seen as very important in the daily onboard work for instance regarding ordering spare parts, maintenance, service, repair and updates. The access to Internet and e-mail are nowadays becoming more common than the lack of it. Only one of the visited ships did not have internet availability in all cabins.

## 11.4 Summary

- Satellite voice communication and cellular mobile telephony in the ECR are facilities that most probably will be present in future ECR communication equipment to meet the new job demands.
- Internet and e-mail facilities are already essential and necessary communication tools in the ECR.

# 12 Administrative Area

| | Ship No: | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| **12 Administrative area** | 12.1 Ergonomic suitable workplace | - | N | Y | Y | N | - | Y |
| | 12.2 Sufficient storage for drawings, books etc | N | N | Y | Y | N | Y | Y |
| | 12.3 Sufficient space for lay out of large scale technical drawings | N | N | Y | N | N | N | Y |
| | 12.4 Sufficient space for PC and peripherals | Y | N | Y | Y | N | Y | Y |
| | 12.5 Sufficient storage possibilities for cleaning material etc | N | N | N | N | N | N | N |
| | 12.6 Suitable placement of the Administrative area in relation to control and monitoring functions. | Y | - | N | N | N | N | Y |

## 12.1 Ergonomic Suitable Workplace

There are qualified demands on a workplace that are to be used commonly. The chair shall be ergonomically designed, computer displays shall be visible and easy to see and placed at a suitable distance. The keyboard and mouse shall be suitably placed as well. Three of the ships were provided with an appropriate area for administrative work and two ships had poorly designed areas allocated for this kind of work (Figure 12.1). The problem with insufficient administrative areas is a common problem for both old and new ships.

*Figure 12.1 A not so ergonomic good administrative area*

## 12.2 Sufficient Storage For Drawings, Books Etc

Order is a condition to facilitate efficient work. Easy access to documentation that is used is one of the components that are important and this require sufficient and appropriate storage facilities. Four of the ships were not provided with enough storage facilities. A common solution is to use the top of the console to store books, binders etc. (Figure 12.2).

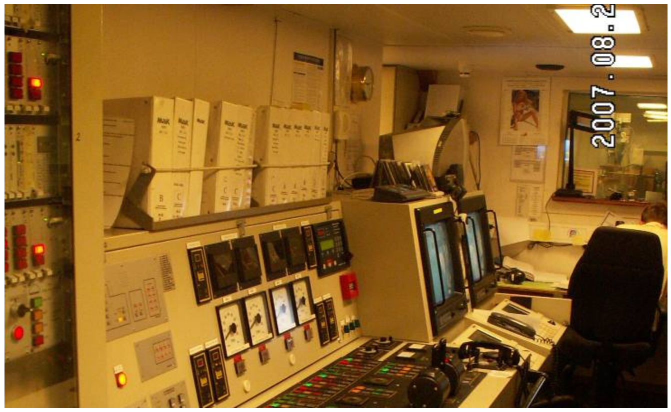


*Figure 12.2 Storage facilities on top of the console*

## 12.3 Sufficient Space For Lay Out Of Large Scale Technical Drawings

Storage is one thing and the possibility of laying out large scale technical drawings is another that is important for efficient work. Large scale drawings need a desk or a wall chart facility to get a sufficient overview. Only two of the ships had the possibility to lay out large scale drawings. One ship had enough desk space and one ship had a coffee table which could serve as a suitable space.

## 12.4 Sufficient Space For PC And Peripherals

An ergonomically suitable workplace shall preferably be placed in a position in the ECR that also facilitate normal operational control and monitoring. That means a central position for the administrative work place as well. This implies that space needed for the PC and peripheral equipment should be nearer to this central place. Often it is the other way round. Where is there space for this new equipment? The answer is often far away from the control console.

## 12.5 Sufficient Storage Possibilities For Cleaning Material Etc

To obtain order in the ECR it is important that there is space for cleaning materials etc. If not one runs the risk of having the material on the floor or other improvised locations hindering efficient work. None of the ships had any storage facilities for this kind of material or equipment. If the switchboards were in the ECR, the space behind the switchboard was frequently used as storage space (Figure 12.3). If the ship had a separate switchboard room, this space was also used for the same purpose.

*Figure 12.3 Behind the switch board*

## 12.6 Suitable Placement Of The Administrative Area In Relation To Control And Monitoring Functions

On two of the ships the administrative area had a suitable placement in relation to control and monitoring functions. On four of the ships this area was placed out of sight and reach of the monitoring area. This as a consequence, resulted in that the engineer had to interrupt his/her work and move to the console every time the process needed attention as the console was normally out of sight and reach (Figure 12.4).

*Figure 12.4 A administrative area placed in a corner of the ECR*

## 12.7 Summary

- The administrative duties are increasing and the design of the ECR needs to take this in consideration by providing the ECR with an ergonomically suitable workplace and ensuring enough space for PC, printers, etc.
- The administrative area should become an integrated part of the ECR and be placed in suitable relation to the control and monitoring functions.
- The ECR should have an area where large scale drawings can be studied.
- ECR design does seldom considers the storage of documentation, tool kits, ship drawings, manuals, cleaning material etc. Generally when an ECR contains switchboards, the space behind these becomes the general storage area for diverse items.

# 13 Briefing / Rest Area

| | Ship No: | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| **13 Briefing/rest area** | 13.1 Suitable meeting area | N | N | Y | N | N | N | Y |
| | 13.2 Suitable rest area | N | N | Y | N | N | Y | Y |
| | 13.3 Sufficient pantry area | N | N | Y | - | N | N | Y |

## 13.1 Suitable Meeting Area

It is of outmost importance to have a suitable area for the team to meet for planning the daily work and briefings. It should be near to but not within the control station area. In the ECRs which are not provided with this type of area, the crew improvise it in some manner (Figure 13.1). This area has many functions; it is a reason for the crew to gather and to get to know each other, visitors are often directed here to talk to the crew and among many things this area is used to socialize over a cup of coffee.

*Figure 11.1 Improvised Briefing/Rest area*

## 13.2 Suitable Rest Area

The rest area may be the same as the pantry/briefing area. The existence of for instance a sofa for a possible rest is also of great importance. There are occasions where it is more convenient for the engineer to be in the ECR all the time, than run in between the cabin getting some short sleeping periods and the ECR. In this case a rest facility is needed.

*Figure 13.2 A rest area with a sofa*

## 13.3 Sufficient Pantry Area

The pantry area or the coffee corner may be included in the same general area as the briefing area. The existence of this pantry is important in many ways. If the coffee break is taken in the mess area, the crew is often split up and the opportunity to get to know each other during relaxed form becomes more limited.

## 13.4 Summary

- The importance of a briefing/rest are must not be underestimated. This area fulfils many demands and serves as a place where information is exchanged, discussions are held, visitors are directed to, job discussions take place and also an area where the crew can socialize and the duty engineer can have a well deserved nap during late night work.

# 14 Conclusions On Board Studies

An on board survey has been performed on seven different ship types within the Swedish merchant marine fleet. These ships represent different ages ranging between 30 years to 6 months old. Detailed observations and measurements of the engine and engine control rooms were included in the study. In the field study observations, different areas have been highlighted. These include: environmental measurements findings, general comments, the layout of the ECR, switchboards, accessibility, console design, alarm management, monitoring outside the ECR, communication, administrative area, briefing/rest area and future work.

## 14.1 Environmental Measurements

As a part of the on board studies field measurements of physical work environment factors have been comprised. The quantities measured are: Lighting, Noise, Temperature, Humidity, $CO_2$, Dust, Vibration and Electromagnetic fields. Unpleasant vibration was registered below the limits put forward by work environmental bodies. Although the electromagnetic fields were within acceptable limits, due to caution a recommendation is to place the control pulpit at a distance to the switch boards to reduce the stay in the proportionately higher electromagnetic field generated by the boards. It is even better to place the switch boards outside the ECR, which may also be motivated by other reasons.

## 14.2 General

The over all conclusion from the field studies is that the design of the ECR:s have not taken the changes in work performance and the development of the engineers' profession into consideration. The problems discussed and addressed by the crew members are very similar, more or less regardless of the age or type of the ship. The most obvious difference between an older and newer ship is that conventional instrumentation has been exchanged for computers without taking the changes in task performance demands which the new type of equipment implies into consideration.

There are substantial amounts of information available concerning best practice when it comes to the design of control rooms. However, the vast majority of this knowledge has in the shipping industry been formulated as non-mandatory guidelines which results in much of this knowledge not being utilized. A future development of rules and regulation concerning this area must assure this knowledge is made use of and also that the way the work is performed is reflected in the design with all aspects of a good working environment taken into consideration.
In brief;

- The design of ECR does not adequately correspond to the role of the modern day engineers and their duties.
- There are non-mandatory standards - but not specifically aimed at ECR, except one IMO document. New standards need to be developed.
- Established guide-lines, rules and regulations are not consequently used and recognised knowledge about HF design and lay-out is often not utilized.
- An overall comprehensive attitude towards the design of an ECR is necessary.

## 14.3 ECR Layout

The shape and size of the ECR has an impact on the possibility to overview the instrumentation and process, the communication pattern between crew members, task performance, maintenance activities and the related movements. The shape and layout needs to facilitate these necessary functions. The predominate requirement which the engineers express is the possibility to overview relevant operational data and status of the engine room and its equipment. A too elongated corridor shaped ECR will make this requirement difficult to fulfil without forcing the engineer to move back and forth. A more square shaped space gives the designer of the ECR possibility to design a proper workplace from where several tasks can be performed under ergonomically acceptable circumstances and where the requirement of a proper overview also is fulfilled.
The introduction of computers in the ECR together with an increase in administrative functions has implied that new work node areas have been developed. As this has not been taken into consideration when designing the ECR, the consequences are that the work nodes are separated from each other which prevents an integration of tasks and work being performed and also render difficulties in the communication.
In brief;

- The choice of shape and size of the ECR provides possibilities but also limitations. The prevailing catchword when deciding the shape is overview.

- The design of the ECR needs to facilitate the integration of different work nodes in order to ensure a proper co-ordination of different tasks and also to ensure an efficient communication.

- The change towards more software controlled systems increases vulnerability and operational risks and provide little opportunities to share information among crew members and the overview of the operational status is concealed in numerous system displays.

- The ECR also need to be prepared for mounting future additional equipment while sustaining a good ergonomic standard.

## 14.4 Switchboards

The placement of the switch board should preferably be in a separate room in close connection to the ECR. Advantages may be found with respect to noise, climate conditions and electromagnetic fields. However, it has to be guaranteed that all operational data which are relevant for the engineers are displayed in the ECR. Maintenance access to the interior of the switchboard and its equipment is much determined by the available area surrounding the switch board. To prevent accidents and offer suitable working conditions, the switch board must be provided with sufficient space to ensure adequate accessibility during maintenance activities.
In brief;

- The switchboards shall preferably be placed in a separate room, surrounded by sufficient space in order to render maintenance activities possible. Relevant control information needs to be presented in the ECR.

## 14.5 Console

The most common shape of console seems to be an straight elongated console. The use of conventional instrumentation requires quite a lot of space and the character of traditional analogue gauges, breakers, switches and signal lamps permitted good visibility over fairly large distances. However, the changeover towards digital displays and the use of computers has implied that a larger amount of information is compressed and displayed with a much poorer visibility, readability and process overview. This calls for a new strategy when the future consoles are designed in order to fulfil all operational functionalities and basic ergonomic requirements which aim at placing relevant equipment within sight and reach. The work in front of computer screens has elements of precision work which also calls for an ergonomic adjustment of the console to provide a comfortable place of work.
In brief;

- The shape of the console should facilitate the engineer having relevant instrumentation within sight and within reach

- The placement of the instrumentation should as far as possible correspond to the actual placing of the equipment out in the engine room.

- The older mimic based control panels provided a single level overview of all systems. Newer digital soft HMI systems provide only a hierarchical keyhole view. To coop with this more and/or bigger computer screens can be used to guarantee that a comprehensive and easy accessible overview is available for all engine crew.

## 14.6 Digital Control System (hardware)

The human – machine interaction hardware associated with the ship’s engineering control systems can be divided into two main groups, one which uses functional keyboards and track ball and one using QWERTY keyboards and a mouse cursor device. The function keyboard compared to the QWERTY implies a reduction in the number of interactive steps required in the execution of simple repetitive commands (stop/start etc.). Furthermore, a fixed trackballs provide an equally as efficient method for cursor manipulation and have the clear advantage of not wandering about due to vibrations and harsh weather conditions.

In brief;

- TFT flat screens are preferable to CRT screens in regards to clarity of display image and resolution.
- Functional keyboards are to be preferred as it facilitates an easier and quicker navigation and function execution.
- The use of a trackball is to be preferred.

## 14.7 Computer Based Interface (Software)

Generally the numbers of displays contained within a computerized system architecture vary from 70 to 114 displays among the investigated ships. This is just displays and not the number of pop up windows etc. that may be incorporated into the system. Two approaches to display design could be noted. One approach is based more upon the Windows approach to interface design and the other is based upon the more traditional semi-graphic approach. Two of the four vessels utilizing soft control used the Windows design approach. There were furthermore inconsistencies in the design with regards to the use of symbols, colours, shapes etc.

- Troubleshooting software problems is a major problem due to a lack of sufficient documentation and/or experience and knowledge of software systems. There is a definite need for extended training of engineers.
- The new digital technology and related HMI does permit more compact instrumentation but at the cost of the overview.
- In general, the functionality of Windows in most cases imply a more complex display structure which requires more operations to be performed in order to execute a task, compared to a semi graphical interface together with a function keyboard design approach.
- System display architectures should be relatively shallow in depth – not more than three levels.
- The interface should permit rapid accessibility for critical emergency functions, eliminating complicated search procedures for the appropriate configuration display. Critical functions may in cases be made redundant by retaining them in a non display based hard control form.
- Reviews on all vessels revealed first inconsistencies in design between displays in a given onboard control system. Secondly inconsistencies are found between stand alone system supplier solutions and the primary control system.
- The use of coding methods such as iconic, terminology, colour, shape etc. needs refinement regarding standardization.

## 14.8 Conventional Instrumentation

The major difference between hard control and soft control from an operator perspective is that hard control involves physical movement to a position and the exertion of some physical force to activate a rotary switch, lever or push button as well as always being available visually and physically. This provides the engineer with a clear overview of the operational status and also with feed-back of executed commands. Two of the older vessels were equipped with specific sequence displays that indicated the sequence of pump start up. This was a feature that the many engineers liked and would like to see in installations, particularity in regards to linked sub-sequences that are activated by a single command.
In brief;

- In newer vessels, console hard control instrumentation is mostly preassembled units provided by different suppliers as final products. This does create a number of problems in consistency of design.
- The development of the integrated control and indicator units neglects design guidelines stating that controls shall be positioned on the console horizontal surface and all displays shall be located on the console vertical surface. Visibility of alarm and state indicators tend to decrease with a placement on the horizontal surface.

## 14.9 Alarm Systems

The number of control signals varied from 800 to 2500 items in the investigated ships. In addition to this, many alarm nodes are spread out in the ECR instrumentation. An adequate overview of all major systems is missing. Neither the alarm displays nor the process graphics provide an optimal method of controlling trends in system changes approaching alarm conditions and which permit pre emptive action before a situation arises.
In brief;

- The alarm signal should indicate whether the alarm is a minor or serious fault cueing the engineer if an immediate action is necessary or not.

- All ancillary sub system alarms need to be consistent with the main alarm management system. Otherwise a situation which is firstly difficult to overview and secondly possibly contributing to misinterpretation can occur.

- Alarm filtering of primary initiating alarms and secondary following alarms related to the initial event as yet is still not used in any of the alarm systems reviewed. It may be advisable to develop a generic filtering module that could be easily modified for specific vessels.

- In diagnosing an alarm situation one may require three displays – the alarm list, a system overview display of the affected system in its entirety and a object detail display.

- Slave alarm acknowledgment panels could be located at strategic locations in the engine space compartments eliminating the need to drop everything and go to the ECR in order to acknowledge an alarm. This may be important on vessels with smaller crews.

## 14.10 Monitoring Outside ECR

A central issue for the ECR operator is to have a good overview of a number of different information sources. To provide the engineers with information from surveillance cameras from various parts of the ship not only give the engineers valuable information to support the decision making process but it also makes the engineers feel implicated of the operation of the ship. Surveillance cameras in the engine room can replace many engineers’ requirements for windows in the ECR over looking the top of the main engine and maybe be a better solution as the cameras can overlook more areas and also can be directed at critical objects.
In brief;

- Possibilities to overlook the ER and other areas of the ship represent an important enhancement of the situation awareness without the need to walk around the spaces. This can be accomplished by cameras in the ER and presentation screens in the ECR.

- An Electronic Chart Information presentation in the ECR will give fundamental information of ship position that is very relevant for the operational decisions.

- Cameras and presentation screens showing different essential parts of the ship and fairway gives a good situation awareness that can be helpful in decision making without the need to ask for checks and information.

## 14.11 Communication

The rapid development of the communication technology has not escaped the ships. The engineer crews and especially the chief engineer becomes more and more dependent of being able to communicate with different shore based organisations, suppliers etc. The decrease in the size of the crew entails the chief engineer having to spend more time in the engine department manning the ECR during departure and arrival etc. It has been an expressed wish from the chief engineers to have full access to the ships communication abilities in the ECR so that the time being spent in the ECR can be utilized fully for work.
In brief;

- Satellite voice communication and cellular mobile telephony in the ECR are facilities that most probably will be present in future ECR communication equipment.

- Internet and e-mail facilities are already essential and necessary communication tools in the ECR.

## 14.12 Administrative Area

The administrative workplace in the ECR needs to be an ergonomically suitable workplace, ensuring enough space for filling out the engineering logs/paper documents, PC, printers, etc. The burden of administrative duties has increased over the years and a lot of time is spent in front of the PC. In most cases the desk is placed in a corner, separated from the console and its monitoring equipment. This is not only attributed older ECR, built when the PC was not a part of the engineers work. The ECR on board new built ships show the same lack of integration of the administrative work place into the monitoring and operation of the engine room. In brief;

- The administrative area should become an integrated part of the ECR and be placed in suitable relation to the control and monitoring functions.

## 14.13 Briefing/Rest Area

The importance of this area seems in some cases to be underestimated. The area has several purposes and serves among other things as a place were the exchange of information can take place, planning of work and discussions on how to accomplish the tasks associated with this. Repair men coming on board are often directed here and the area gives the opportunity for the crew to socialize over a cup of coffee and also to relax. Last but not least, during situation with long working hours and interrupted sleep the duty engineer can have a well deserved nap during late nights work.
In brief;

- A Briefing/Rest area is of great importance and need to be carefully planned for.

## 14.14 Future Work

The design of the ECR needs to be developed. The existing rules and regulations permit a wide range of design solutions not always well thought-out. Therefore the existing rules and regulations needs to be developed towards a function based set of rules and regulations. How the tasks in the ECR are performed needs to be taken into consideration and the different functions and their interaction in the ECR need to be defined. Future rules and regulations need to take these issues into consideration. An IMO steering document providing the general framework and ISO level details for designers, shipyards etc are required. Furthermore a future set of rules and regulations need to assure the existing knowledge and applicable design standards can be incorporated into a new standard for ECRs

The future work in the engine department needs to also include the engine room, ER and its specific questions at issue. A similar methodology to the ones used in the ECR can be used as any changes in the design of the ER need to be based on the different task demands and functions specifically related to the work in the ER.