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INTEGRATED PLATFORM MANAGEMENT SYSTEM ON NAVAL SHIPS

– Applicability study



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The goal of this thesis was to give information and raise up new ideas for the start of detailed design of integrated platform management system. What could be expected, what kind of features could be beneficial, what is the reason for such a system, and can it help with requirements like better survivability with leaner manning? This work is not concentrating on some specific feature, it is intended to offer a broader look on the topic. Broader view was seen as the best and most usable result for this kind of work.

The aim was to form a good picture of what the limitations are on current ships and how the situation could be improved. The first step was to interview system experts who have deep knowledge about the systems and current issues. During the interviews these experts were asked questions like what the problems with current system automation are and are there any systems which are lacking information that is available in other systems but is not shared. From these interviews a few areas of interest were formed. Literature review was used to gather more information to each subtopic.

The result of this thesis is that yes, integrated platform management system can be an asset to improve ship and its crew performance. It is also clear that the integrated platform management system must be designed for the ship, taking into account what it is used for and where. For smaller and simpler ships used against inferior enemy or in less hostile environments simpler integrated platform management system with features focusing to ease of use, maintenance costs and lean manning could be the best option. For larger and more complex ships used against advanced enemy, features could concentrate on better survivability by implementing features for better situational awareness and advanced recoverability functions.

KEYWORDS:

IPMS, Survivability, automation

Waltteri Kaikkonen

INTEGROITU ALUSTANHALLINTAJÄRJESTELMÄ MERIVOIMIEN ALUKSISSA

- Käyttökelpoisuuden arviointi

Tämän opinnäytetyön tavoitteena oli antaa tietoa ja kehittää uusia ideoita integroidun alustanhallintajärjestelmän yksityiskohtaisen suunnittelun aloittamiseksi. Mitä järjestelmältä voidaan odottaa, millaisista ominaisuuksista voisi olla hyötyä ja voiko se auttaa sellaisissa vaatimuksissa kuten parempi taistelunkestävyys tai pienempi miehistön määrä? Tässä työssä ei keskitytä yhteen tiettyyn toiminnallisuuteen ja sen loppuun asti suunnitteluun. Nykyiseen tietotarpeeseen vastaa paremmin aihealueen laajempi tarkastelu.

Ensimmäinen vaihe oli muodostaa ymmärrys nykyisten järjestelmien rajoituksista aluksilla, sekä siitä miten tilannetta voitaisiin parantaa. Tämä vaihe suoritettiin haastattelemalla järjestelmäasiantuntijoita, joilla on syvälliset tiedot järjestelmistä ja niihin liittyvistä haasteista. Haastattelujen aikana asiantuntijoilta kysyttiin mm. millaisia ongelmia nykyisissä järjestelmäautomaatioissa on ja puuttuuko yksittäisiltä järjestelmiltä tietoa jota olisi muiden järjestelmien tiedossa, mutta tietoa ei jaeta. Haastatteluiden pohjalta muodostettiin aihealueita, jotka otettiin paremman tarkastelun kohteeksi. Jokaiseen aihealueeseen kerättiin lisää tietoa kirjallisuuskatsauksen kautta.

Opinnäytetyön lopputulemana on, että integroidusta alustanhallintajärjestelmästä voi olla hyötyä laivan ja sen miehistön suorituskyvyn parantamiseksi. On myös selvää, että integroitu alustanhallintajärjestelmä on suunniteltava alukselle ottaen huomioon, mihin alusta käytetään ja missä. Pienemmillä ja yksinkertaisemmilla aluksilla, joita käytetään heikompaa vihollisia vastaan tai aluksilla toimitaan vähemmän vihamielisissä ympäristöissä, yksinkertaisin integroitu alustanhallintajärjestelmä, jossa ominaisuudet keskittyvät helppokäyttöisyyteen, ylläpitokustannuksiin ja pienempään miehistön määrään voivat olla paras vaihtoehto. Suuremmille ja monimutkaisemmille aluksille joita käytetään edistynyttä vihollista vastaan, ominaisuuksissa tulee panostaa parempaan taistelunkestävyyteen keskittymällä ominaisuuksiin, jotka parantavat miehistön tilannetietoisuutta ja edistävät vaurioista palautumista.

ASIASANAT:

IPMS, Taistelunkestävyys, Automaatio

CONTENT

LIST OF ABBREVIATIONS (OR) SYMBOLS	6
1 INTRODUCTION	6
1.1 Background	6
1.2 Problems and targets	7
1.3 Limitations	8
1.4 Text structure	8
2 INTEGRATED PLATFORM MANAGEMENT SYSTEM NOW	9
3 RECOGNIZED AREAS OF INTEREST	12
4 FINDINGS	14
4.1 General requirements for Integrated Platform Management System	14
4.2 Maintenance system and logging	15
4.3 Operational features	17
4.3.1 Engine and propulsion control	17
4.3.2 Power management	19
4.3.3 Interior communications	21
4.3.4 Lighting control	22
4.3.5 Electromagnetic environment	23
4.3.6 Bridge systems	24
4.4 Survivability	25
4.4.1 Video surveillance	27
4.4.2 Platform resource coordination	28
4.4.3 Hatch monitor and control	30
4.4.4 Heat, ventilation and air conditioning	31
4.4.5 Stability calculation	32
4.4.6 Noise	34
4.4.7 Fire alarm	35
4.4.8 Cyber security	36
4.5 Testing of the system	39
5 COULD INTEGRATED PLATFORM MANAGEMENT SYSTEM AFFECT THE OUTCOME	42

5.1 USS Fitzgerald collision with ACX Crystal	42
5.2 USS McCain collision with Alnic MC	45
5.3 HMS Sheffield sinking	47
5.4 HNoMS Helge Ingstad and Sola TS collision	49

6 CONCLUSIONS **52**

6.1 Summary	52
6.2 Recommendations and directions for further research or development	55

REFERENCES **56**

FIGURES

Figure 1, HMS Queen Elizabeth IPMS functional Diagram (Davies & Jewell, 2015)	10
Figure 2, Diesel Engine Components Case Study Model (Dikis etc, 2014)	16
Figure 3, Star Plot of Survivability for the Three Frigate Designs (Piperatkis, 2013).	27
Figure 4, Cyber security assessment sequence (DNV-GL, 2015)	37
Figure 5, UNIC C3 architecture (Wärtsilä, 2018)	39
Figure 6, Starboard side damage to USS Fitzgerald (Department of the Navy, 2017.)	42
Figure 7, integration overview without IPMS	53
Figure 8, integration overview with IPMS	54
Figure 9, IPMS feature overview	55

PICTURES

Picture 1, Hatch with scuttle, marked with Z. (Department of the Navy, 2017.)	43
Picture 2, Damage on the USS McCain (Department of the Navy, 2017.)	46
Picture 3, HMS Sheffield after it was hit by an Exocet missile (The Guardian, 2017)	47
Picture 4, Sola TS observed from HNoMS Roald Admundsen. (aibn & daibn, 2019)	50

LIST OF ABBREVIATIONS (OR) SYMBOLS

3D	Three dimensional
ADC	Analog to Digital Converter
AFFF	Aqueous Film-Forming Foam
AIBN	Accident Investigation Board Norway
AQAP	Allied Quality Assurance Publications (NATO)
ATEX	ATmosphères EXplosives
BDA	Battle Damage Assessment
BIMCO	Baltic and International Maritime Council
CBRN	Chemical, Biological, Radiological, Nuclear
CCM	Cylinder Control Module
CIC	Combat Information Centre
CM	Condition Monitoring
CMS	Combat Management System
CO	Commanding Officer
COMMS	Communications
CORBA	Common Object Request Broker Architecture
COTS	Commercial off-the-shelf
DAIBN	Defence Investigation Board Norway
DDS	Data Distribution Service
DINA	Distribution of Navigation signals
DNV GL	Det Norske Veritas and Germanischer Lloyd
DPA	Designated Person Ashore
DSAC	Damage Surveillance
ECDIS	Electronic Chart Display and Information System
EMCON	Emission Control
EME	Electromagnetic Environment
EPCAMS	Electrical Power Control and Management System

ESM	Electronic Support Measures / Engine Safety Module
FAT	Factory Acceptance Test
FDF	Finnish Defence Forces
FDFLOGCOM	Finnish Defence Forces Logistic Command
FN	Finnish Navy
GA	General Arrangements
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GUI	Graphical User Interface
HAT	Harbour Acceptance Test
HF	High Frequency
HMS	Her Majesty's Ship
HNoMS	His/Her Norwegian Majesty's Ship
HQ	Headquarters
HVAC	Heating, ventilation, and air conditioning
I/O	Input / Output
IAS	Integrated automation system
IBS	Integrated bridge system
ICD	Interface Control Document
IFF	Identification, friend or foe
INCASS	Inspection Capabilities for Enhanced Ship Safety
IOM	Input/Output Module
IP	Internet Protocol
IPMS	Integrated platform management system
IT	Information Technology
KNM	Kongelig Norske Marine
KVM	Keyboard Video Mouse
LCP	Local Control Panel
LDU	Local Display Unit
LOP	Local operator panel

MCAS	Machinery Control and Surveillance
MCM	Main Control Module
MCR	Machinery Control Room
MIT	Ministry of Infrastructure and Transport
MRSC	Maritime Rescuer Sub Centre
MSB	Main switchboard
N/A	Not applicable, not available or no answer
NATO	North Atlantic Treaty Organization
NVG	Night Vision Goggles
OEM	Original Equipment Manufacturer
PA	Public Access
PAGA	Public Access and General Alarm
PCS	Propulsion Control System
PDM	Power Distribution Module
PMS	Power / propulsion management system
POBT	Platform Onboard Trainer
RADHAZ	Radiation Hazard
RCS	Radar cross-section
SAR	Search and Rescue
SAT	Sea Acceptance Test
SI	Système international d'unités
SIF	Shore Integration Facility
STANAG	Standardization Agreement (NATO)
STW	Setting to Work
TCP/IP	Transmission Control Protocol / Internet Packet
TV	Television
UNIC	Wärtsilä Unified Controls
US Navy	United States Navy
USS	United States Ship
VPN	Virtual Private Network

WW2

World War 2

1 INTRODUCTION

Integrated platform management system (IPMS) is a system which can control and monitor all the needed ship subsystems from propulsion to hatch control. If IPMS is compared to a more traditional machinery control or integrated automation systems (IAS) found on commercial ships, the IPMS is more or only intended for Naval applications. There are lots of similarities and no clear line can be drawn between IPMS and IAS. Most clearly distinctive features are related to the battle damage control features of the IPMS. There is no shelf IPMS solution which would fit for everyone, each installation needs to be designed to meet the applicable requirements. On high level the need could be to decrease the size of crew, increase reliability or increase survivability. There is no limitation on vessel size, so very simple solution can be adequate for small vessels while more complex ship can utilize the whole benefit of full feature IPMS.

1.1 Background

New ship projects on Finnish Defense Forces Logistic Command (FDFLOGCOM) are starting in quite steady intervals. At the same time when these projects are starting or ongoing there is constant pressure from the Navy to have more performance with less crew. In addition, FDFLOGCOM is giving pressure to limit the maintenance and life-cycle costs of the ships. Could both requirements be fulfilled by increasing the level of automation? Because IPMS is a new topic for FDFLOGCOM and there is limited amount of experience or other information available from open sources, this thesis is intended to give more ideas for the start of the ship design phase. This is achieved by raising up issues with current systems and finding out features which could benefit the end user or maintainer.

Finnish Navy ships have had modern automation systems for a long time. But currently most of the automation systems on board are standalone. Standalone in this case means that they are not interfaced to any other system and for all information needs they have provided their own sensors or other information input method. Some systems like the Integrated bridge system (IBS) have of course interface to other systems like the Integrated automation system (IAS) or propulsion and rudder control, but in many other systems the operator is the interface. The operator can see what a system is displaying

and with that information they can control another system. With highly trained and experienced crew which doesn't make mistakes this is a good way of making things work. But using humans can be quite expensive. They must be trained for a long period, they can decide to change position or leave completely, and they need to get paid constantly. Accommodation, food, drink and entertainment must be arranged onboard the ship. During wartime they can be easily lost and are difficult to replicate.

Of course, standalone systems have their benefits. Several independent standalone systems are easy from the procurement and installation standpoint. Testing can also be simple and done maybe even by a single system provider or Original Equipment Manufacturer (OEM). No difficult tri-lateral contracts or interface specifications are needed. Just good old form fit function requirements which are usually quite straight forward, and no one needs a degree on business laws to understand them.

1.2 Problems and targets

Requirements like the lean manning or increased survivability may force designers to think beyond this standalone situation. Could integration of some systems into a single system help meeting these requirements? How to know which are the systems benefitting the most from integration to another system? How to know what to require and expect from IPMS? A good starting point would be an applicability study on what features should be studied more closely.

Is IPMS a good and valuable asset for ships made for different applications or ships with different sizes? What is the main reason to even consider such a system? What features it should have to be an asset to the crew? How reliable it can be and when it malfunctions could it be a liability? Should some systems be controlled by IPMS or should it be more of an observer. This thesis tries to answer at least to some of these questions by including interviews of sub matter experts, by looking into accident reports and other literature work related to IPMS.

On the early stages of this thesis it was discussed if it should concentrate on narrower area to be able to go into deeper details. However, it was decided that for Finnish Defence Forces (FDF) the most useful result is a broader view of the topic.

1.3 Limitations

This work is not going to be market review or evaluation of existing systems. The style of this thesis is not going to be a scientific research, but more like a development work. The features listed in this thesis are not covering all the possibilities but are concentrating on a few which seemed most interesting during interviews. Combat system is limited to only provider or receiver of information and combat management system (CMS) features are mostly left out. The references for this thesis are based only on unclassified information and open sources, but the names of interviewees are not released. Many of the ideas for future systems which came from the interviews or from the author are not complete, e.g. the idea that something should be measured to benefit something. How the actual measurement is done or are there suitable sensors on the market or could they be developed is not part of this thesis. No simulations or modelling are made for this thesis.

1.4 Text structure

To give perspective what the state-of-the-art solution should be these days there is in chapter 2 a high-level brief on Her Majesty's Ship (HMS) Queen Elizabeth and how the IPMS is implemented in it. Chapter 3 describes in more detail the topics to be researched. Chapter 4 will describe the results and in chapter 5 four accidents are reviewed with an estimation of if IPMS could help on those situations. Chapter 6 contains the conclusions of this thesis.

2 INTEGRATED PLATFORM MANAGEMENT SYSTEM NOW

From magazine articles and system supplier brochures it could be felt that IPMS is a system which is appearing in many places but very little real information can be found. Naval ships and their detailed design are probably never going to be an openly discussed topic in public. From older ships like the HMS Sheffield some information could be found but its availability is limited and acquiring such information is not in the budget of this thesis. If this thesis work is trying to look into the future, probably not much useful information could be found on ships which are commissioned earlier than 90's and are not upgraded with IPMS.

From these public sources it can be seen that at least some Navies have seen the benefits of IPMS. The Spanish Armada has developed its own system and mandated that all current and future ships shall use it. (Defence SA Advisory Board, 2009). According to Naval-technology online magazine (Naval-technology 2019) L-3 MAPPS's IPMS have been delivered to multiple customers, including US Navy, German Navy, UK Royal Navy and French Navy. Even if the information from this kind of marketing material must be taken cautiously it could be stated that there are multiple navies using IPMS in at least some of their ships.

HMS Queen Elizabeth is the newest class of aircraft carriers for the Royal Navy. She is a 280 m long with displacement of 65 000 tonnes. While powered by two Rolls-Royce MT30 gas turbines providing over 70 MW and four diesel generators providing 40 MW she can reach speeds up to 32 knots. The range can be up to 10 000 nautical miles. She can accommodate the maximum of around 50 aircrafts including helicopters and F35 stealth fighter-bombers. The initial operational capability should be reached by the end of 2020. (Allison, 2017; Royal Navy, 2019.)

HMS Queen Elizabeth class aircraft carriers have been designed for lean manning and IPMS is one part of this design. These aircraft carriers have 20 % of the crew of the US Nimitz Class even though they are 60 % of the size. The access to the IPMS is handled by 65 IPMS operator stations and 12 IPMS laptops which all have full access to the system. Systems fully integrated into IPMS are Electrical Power Control and Management System (EPCAMS), Machinery Control and Surveillance (MCAS), Damage

Surveillance (DSAC), Condition Monitoring (CM) and Platform Onboard Trainer (POBT). In HMS Queen Elizabeth IPMS is working on restricted and secret internal networks. IPMS instance working on secret side is also connected to the Combat Management System (CMS). For the network IPMS is using 100 Mbps Ethernet / Internet protocol (IP) network and 1 Gbps bandwidth between nodes. (Davies & Jewell, 2015)

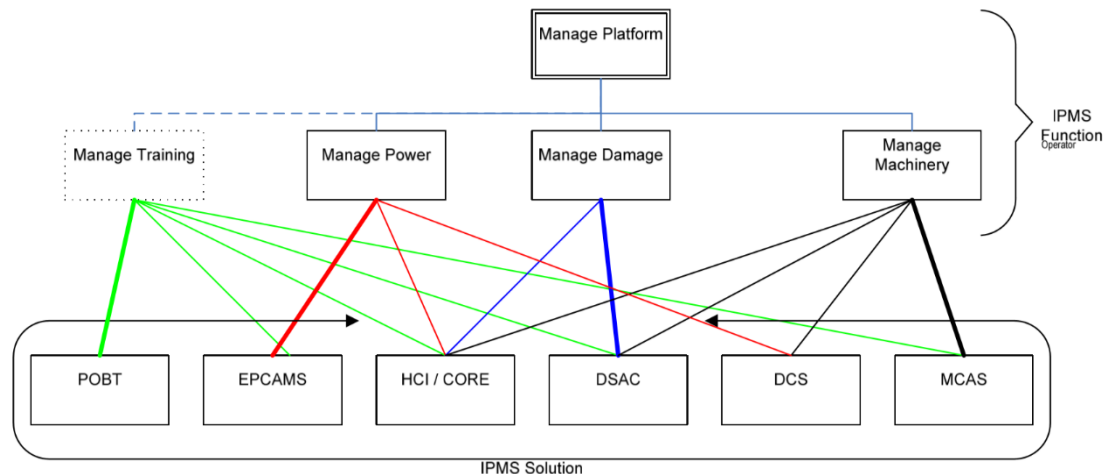


Figure 1, HMS Queen Elizabeth IPMS functional Diagram (Davies & Jewell, 2015)

HMS Queen Elizabeth class aircraft carriers are divided into five damage control zones. Each of these zones have IPMS control stations. This will give flexibility to the operators when they can use any of the control stations and they are not dependent on any single control station. Each control station can work in standalone mode without connection to network or common servers and they are always kept synchronized. To increase the effective decision making common real time situational picture is always available on these control stations. (Davies & Jewell, 2015)

On HMS Queen Elizabeth the IPMS can display multiple different layers of information. The level of detail can be adjusted and live status from systems can be added to general arrangements style of overview. The operator can plan by directly drawing to the large screen displays and transmit those drawing to other IPMS consoles. System failures and action damage reports can be followed from the IPMS display, this permits fast exchange of operational priorities by prioritizing them to meet ships Command Aim. (Davies & Jewell, 2015)

Kill Cards which informs the user what tasks need to be executed in different damage control situations are included in HMS Queen Elizabeth's IPMS. There are up to 10 000

Kill Cards in the system, some of them allow semi-automatic or even fully automatic actions based on the situation. (Davies & Jewell, 2015)

Individual IPMS control stations on the HMS Queen Elizabeth can be put on simulation mode even when the others are in real world mode. Full functionality of the system can be simulated. (Davies & Jewell, 2015)

3 RECOGNIZED AREAS OF INTEREST

This development work started from evaluating the status of different systems. Status in this case means how the systems are functioning in principle. How they are interconnected to other systems or are they stand alone. Could they benefit from information fed by some other system? Or could they provide valuable information to other systems. This overall picture was formed by interviewing system experts, naval architects and ship personnel. The names of the interviewees and memos of the interviews are saved but not released on this work.

Five different main topics were identified during the preliminary assessment of this thesis.

1. General requirements for IPMS, this topic will include general requirements related to the IPMS itself.
2. Maintenance system, what features of IPMS could benefit the maintenance aspects of the ship
3. Operational features, which features could make the crew's life easier or advance the lean manning.
4. Survivability, could some features of IPMS increase the ships survivability
5. Testing, difficulties and how to mitigate integration risks

Interviews conducted for this thesis were performed in free flow conversations without following exactly any scientific research method. Interviewees were asked questions like: are there any problem areas on current system automation or would some systems benefit from data provided by some other system. Quite interesting discussions were started by these questions. Typically, at first the interviewees were a bit puzzled why they are asked this kind of questions and there was a bit of change resistance towards the whole topic. But when common understanding was achieved on what this topic is all about, the attitudes changed a bit. Many of the answers reflected on past bad experiences of failed or somewhat problematic integrations. Many promises have been made by system suppliers in the past but still result may vary. Our organization is very lean manned, so the total amount of interviewed experts was only 7. A single person can be responsible for multiple different systems, so good coverage of different systems was still achieved. Interviews are numbered from 1 to 6 in references section. In interview 1 there were two persons present.

The ideas proposed on this work are a combination from the interviews, outside sources and findings during this work.

4 FINDINGS

4.1 General requirements for Integrated Platform Management System

In some of the interview it was seen that IPMS should display information but not necessarily control everything. Some interviewees had the opinion that the connection between IPMS and other systems should be two way but with limitations. (Interviews 1, 4 and 5, 2017.) The conclusion is that it should be carefully evaluated what features are really needed and give control for only those.

The requirement repeated multiple times for different occasions was that the IPMS cannot be too complex. One fear was that for example fault tracing is going to be impossible if every system is integrated into one. Past experiences have shown that even in simple two system integrations totally irrelevant failures may reflect to operations. One interviewee mentioned that failure in autopilot system was causing issues in IAS system. (Interview 3 and 5, 2017, Interview 2 2019.)

One interviewee was also concerned about the feeding and distributing of incorrect information. According to him it must be somehow prevented that only correct information can be passed along the system. (Interview 5 2017.) This issue could probably be solved or limited by firewalls or filters which are capable of deep packet inspection if IP / Ethernet type network is used.

One interviewed system expert was concerned about if some part of IPMS fails, it shall not affect the whole system or require a total reboot. (Interview 5 2017.) It is obvious that startup and shutdown procedures should be free.

If connection is lost every system shall function also as standalone without IPMS and manual override must be implemented. These two requirements also came up in interviews. (Interview 3, 4 and 5 2017, Interview 2 2019.)

With high number of sensors how to detect if sensor is reading wrong, has failed or is completely missing? Reading not available (N/A) is a completely different thing than reading zero. This is easily solved if single or few different sensor types are used. But in the case of full spec IPMS the number of different sensors can be high. Environmental requirements for the sensors must be considered carefully, which sensors must work submerged or which must stand extreme heat.

If the ship where an IPMS is installed is going to be classified there can be rules from the class society. For example DNV-GL Part 4 System and components, Chapter 9 Control and monitoring systems give a good list of requirements for systems like the IPMS. Starting from classifying the IPMS, certificating different features, software development, testing, human interface design and lots of other details. (DNV-GL, 2015)

In addition to the class society rules other requirements may rise depending on the platform and planned missions. On MHS Queen Elizabeth class aircraft carrier's a maximum latency of two seconds for any input or output was required (Davies & Jewell, 2015). This kind of requirement could increase the probability that the IPMS is displaying correct data and the control commands are going through. If typical office grade commercial off-the-shelf (COTS) hardware with non-real-time operating systems are used, the latency is always a guess or calculated prediction.

4.2 Maintenance system and logging

In the interviews it was brought up that IPMS could show maintenance notifications, gather operating hours of different system and feed the maintenance system with this information. Currently engines are usually maintained according to usage time or just calendar. This centralized maintenance system could make the calculations but IPMS could show the alarm and forward the information to IAS system. For example from pump connected to IAS, IPMS gets the data and sends it to the centralized maintenance system. Some centralized maintenance systems can be interfaced to IAS. But IPMS could be a better node for this kind of complete maintenance system. IPMS could gather fault information from multiple different systems and sensors like fire alarm. (Interviews 3, 4 and 5 2017)

An area of interest was also logging of what systems have been used and how they have been used. This could help finding random looking faults and interference sources. In the IPMS there should be a tool to analyze this information. IPMS could have a lot wider knowledge about what is happening around the ship than compared to traditional IAS system. This should not only be for engine usage profiles but also other systems including combat system. Data should be automatically analyzed to find anomalies. Vibration and stretch measurements should probably be sent to shore for analysis. (Interviews 3, 4 and 5 2017)

Maintenance tablet with extensive connection points or with wireless connection to IPMS could help problem solving. The maintainer could stand next to the unit with issues and see sensor data or control the unit. Access to all data should be available when needed. According to the interviews on many currently used systems you can only access some features with laptop but not all. (Interviews 3 2017.)

As stated by Dikis et.al. (2014) vibration monitoring is the most known and applied technique of condition monitoring. In MHS Queen Elizabeth permanent vibration transducers on approximately 200 rotating machines will be connected to IPMS and hand-held recorders can also be used. (Davies & Jewell, 2015)

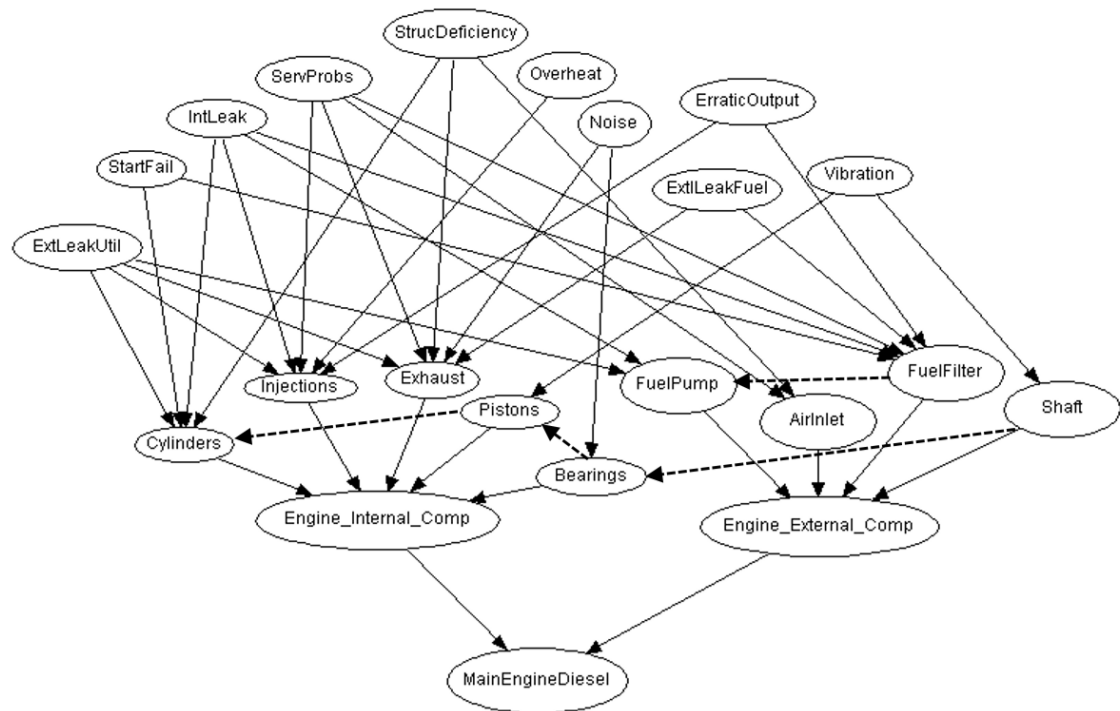


Figure 2, Diesel Engine Components Case Study Model (Dikis et.al., 2014)

In Inspection Capabilities for Enhanced Ship Safety (INCASS) project a case study was performed where main engine, engine block, cooling system and their failure modes were considered. The input for the analysis was historical data, expert input/judgement, oil analysis and live measurements from vibration or thermography sensors. All this information was processed through different tools in the INCASS framework and the result showed acceptable operational levels of reliability performance. (Lazakis et.al., 2016.)

INCASS framework seems like a very sophisticated way of helping with condition-based maintenance. Such features could be a part of IPMS or at least it should be considered if IPMS could feed this kind of system with data.

Real time logging of the whole ship needs accurate ship wide time synchronization. Also, the habit of making a note of the exact failure time is crucial if the IPMS is not able to detect the failure: Which systems were running and how when the failure occurred. Automatic checking of history if similar situations have happened and also checking if something failed at that time.

IPMS system could be the system with most wide variety of sensors and access to all data gathered by other systems. This gathered data could be used to predict maintenance needs and isolate fault conditions. Also, this data can be an asset when developing new ships. High level of automation is needed as well as usage of specialized software or artificial intelligence type of applications. The amount of data is going to be so high that going through it manually can be too time-consuming task for humans.

4.3 Operational features

Operational features in the context of this thesis are including features which can be useful to maintenance or simplify usage of the platform. They may not necessarily increase survivability but can be helpful in other situations.

4.3.1 Engine and propulsion control

According to the interviews currently used machinery control systems or integrated automations systems (IAS) control a lot more than just machinery and propulsion. It was suggested that it could be reasonable to leave IAS as machinery and propulsion control system and move other features into the IPMS. It was also seen that IAS may not need much information from IPMS but could offer a lot of information for other systems. (Interview 5 2017)

In the casualty of United States Ship (USS) McCain there was a lot of confusion on the steering and propulsion control (Department of the Navy, 2017). When the ship has lot of different control systems from different system suppliers, they may have different logic of how the user interface works. All of them tend to have their own style in the graphical

user interface (GUI) and every software has its bugs or features. Some interfaces can be very intuitive with one physical adjustment wheel while with some others can have hundreds of buttons in computer display and very little can be done without proper training. When you add all quirks and features to the mix it can be even too difficult for users to work in emergency situations without long experience on that exact system. In surprising situations like in the USS McCain the crew from another vessel was not completely familiar with all the features and mistakes were made. This can eventually lead to a situation where training of the crew in multiple different ships comes very difficult or impossible.

With one system integrated to multiple different systems some benefits could be gained with common style of user interface. Similar symbols, similar arrangements in the GUI, similar look and feel of the system could make the operating of different ships safer. In MHS Queen Elizabeth class aircraft carriers the Machinery Control and Surveillance (MCAS) is integrated into IPMS (Davies & Jewell, 2015). There could also be some sense behind the Spanish Armadas decision to install the same IPMS in every ship and even retrofit the old ones (Defence SA Advisory Board, 2009).

If very critical functions like engine, propulsion or steering control is added to a system like IPMS, it should also affect the reliability requirements for the IPMS. It should be very hard for the IPMS to lose control and even if the control is lost the backup systems must be ready to take control. On USS McCain when the control was changed from station to another. The value of requested rudder angle changed depending what was selected on the back up station before the control change (Department of the Navy, 2017). This kind of issues should be avoided and to avoid it there should be constant change of information between the backup system and primary. Of course, it should be considered if in some situations returning all values to default or zero is the best solution.

Engine control from the IPMS could be only high-level commands. Start up, shutdown, combat override and engine speed can be enough in most of the cases. It is difficult to see any real added benefit from controlling very low-level engine parameters like fuel injection timing. This would add complexity and integration difficulty. Even these low-level parameters could still be monitored. More information the IPMS is getting the better it can serve other systems like the centralized maintenance system.

If the IPMS can record data, it could be made to learn from experience. When crew orders the machinery to do something, some other system should be prepared for this.

One example could be the power management system: when operator suddenly throws throttle from 0 to 100 and the electric motors start to eat power, what happens with the power production in total including the hotel load. Or calibrate constantly what the correct pitch of the propeller is for any given situation to achieve least noise or best efficiency.

4.3.2 Power management

In interview 3 it was seen that a change of switchboard feed from A to B could be made in advance if it could be predicted that cable problems are going to occur. Feeds to most important parts like the combat system or propulsion should have high level of redundancy. (Interviews 3 2017)

In the interviews it was seen that maybe power management system (PMS) could be a standalone system or part of IAS. The amount of running auxiliary engines should be controlled depending on the load. Also, it was seen that PMS should have interface to IPMS. (Interviews 4 and 5 2017)

Each genset has a local operator panel (LOP) which could be used to override IPMS control. (Interviews 4 2017) On MHS Queen Elizabeth class aircraft carriers the Electrical Power Control and Management System (EPCAMS) is integrated into IPMS. In two positions there is still direct access to EPCAMS if IPMS has failed. (Davies & Jewell, 2015)

According to the interviews there are quite often questions about the quality of the electricity. Harmonic distortions, currents and other interferences should be monitored by the IPMS and sent to datalogger. This kind of power quality monitoring could greatly help with fault finding. (Interviews 4 and 5 2017)

In one interview it was also proposed that isolation resistance measurement for 690V and 440V could be done by IPMS. In current systems the measured areas are quite large and higher resolution would be beneficial. (Interviews 4 2017)

If the IPMS is integrated with CMS, it could get information to evaluate where the ship is going to be hit to do necessary adjustments in advance. These pre-emptive measures cannot affect the combat systems in this very crucial moment, but they could increase the survivability of the ship. Power production related measurements could be done, for example electrical isolation of spaces or switchboard changes.

TEMPEST and RED/BLACK separation have been challenging designers for many years now. The codename TEMPEST has its initial roots in the WW2 when it was discovered that electrical emanations allowed secret information to be read from the ciphered side of a cryptographic device. Today TEMPEST is still a codeword for compromising electromagnetic radiation which can contain sensitive information. To avoid this radiation and interception of it, some design precautions must be made. RED/BLACK separation is strongly related to TEMPEST and the idea is to keep the signals containing secret data or audio in plain form from mixing with signals containing ciphered or unclassified signals. There are multiple TEMPEST related NATO standards for installation, equipment and testing to help with the design. But online testing is not that widely or openly discussed topic. Could IPMS be used to do online testing and monitor if red/black separation is still working at any given time? To make this work the IPMS should monitor the signals on the red (secret) side and compare this to the signals found on the black (unclassified) side. An other way could be resistance or attenuation measurements from different cablings like power or groundings. This would probably introduce security issues of its own but it could be done.

With historical data IPMS could estimate what the ship's performance is at any given time. During normal operations it can be verified if excessive power is needed compared to the speed and estimated hotel load. Ice load system could also be used as source or end point for data or it could be even fully integrated in to the IPMS. Also, if the ship is damaged, especially by complex battle damage, it may not be very clear what the ship's capabilities currently are. Is there increase in drag, how much liquids were lost, how much power is available for propulsion or combat systems, what the maneuvering capabilities are or how much time there is before stability or power is lost. This information with environmental information such as maps and temperature could give indication where the ship should be moved for the safest anchoring or grounding or where the best chance is for the crew to survive if the ship will sink. Before this kind of system is implemented human reaction to non-survivable estimations should be considered. Should the system be positive till the end to avoid other human reactions due miscalculation.

4.3.3 Interior communications

Modern integrated intercom and public address / general alarm systems are quite versatile. Data or audio interfaces can be integrated to multiple sources and one of those sources could be the IPMS.

General alarms shall be sounded through the Public Access and General Alarm (PAGA) system. The actual alarm tone or sequence could be generated by the IPMS or intercom but probably the simplest option is the PAGA system. Audio interface between IPMS and PAGA would be simple for integration. But what if one of those alarms needs to be launched somewhere else than in the IPMS control station? Intercom is one of the widest spread system around the ship, only electricity and lighting is more available. Current generation of intercom systems can offer the user the ability to initiate alarms from the intercom user terminals. They are connected by data to the PAGA systems and it will play the alarm requested by the intercom. It could be better that IPMS also initiates the alarm similarly by just giving information to PAGA system for which alarm to play.

Using PAGA system for all alarms could also have a benefit of limiting the total amount of needed speakers on the ship. Redundant PAGA system is accepted by class society and a third layer of alarm speakers or bells may not be needed.

Some intercom systems have the possibility to add wireless handheld devices to the network. Some of these solutions are based on COTS smart phones connected to a ship wide wireless network. From IPMS point of view this could be one way of sending information and receiving information. For example machinery alarms or status information could be directed to the device used by the chief engineer.

If the ship is fitted with info TV -system it should be connected to IPMS to automatically display alarm information.

Many of the accident reports addressed in chapter 5 mentioned the difficulty to count the crew. Intercom devices connected to IPMS could provide a way to report your status and position directly to the system. There are probably better dedicated systems for this but it could be an alternative solution.

4.3.4 Lighting control

IPMS could take control of the lighting system of the ship. On naval ships there is a need for different presets for different operational conditions. Brown or red lights are commonly used inside the ship during dark hours. Deck lights are usually off but if they are on there can still be limitations to what kind of light is allowed. During dark time missions' operators using night vision goggles may not be blinded while the crew who is not using night vision goggles (NVG) should still see something. Controlling these aspects from IPMS could limit mistakes especially if they can cause life threatening accident or decrease the survivability.

On USS Fitzgerald survivors from the flooded berthing said that only the combat lanterns system was steering them to the right direction (Department of the Navy, 2017). If the lighting system controlled by IPMS has ability to control single light or small groups of lights, they could provide guidance to safety. This would mean that the IPMS system should have complete situational picture and capability to assess the situation or present the situation for the crew to aid decision making.

If the lighting system is sophisticated enough light color and intensity could change depending on location of light source. Light closer to the exits would be closest to outside conditions while light deep inside the ship would be whatever is needed. This may be a bit of a luxury type of feature and not much effort should be put to it. But if the lighting system allows this kind of light manipulation, there could be slight advantages to be gained.

Even if modern warships will detect each other in mainly non optical way, the lighting can still affect the detectability of the vessel. Hybrid threats are still existing and often this kind of warfare includes usage of old weaponry which may be based on optical detection and aiming with human eyes. To increase survivability against these hybrid threats some old school World War 2 (WW2) era tactics could be implemented with ship lightning. For example usage of deck lights to make it difficult to estimate heading or using certain patterns of light so the ship would match fishing boats or similar.

4.3.5 Electromagnetic environment

Depending on the top side design there may be areas which are not safe for personnel when some radio frequency transmitters are used. Radiation from them is usually not visible for human eyes and cannot be immediately felt. Sensors could be used to measure the field strength and alert nearby users of the possible danger. If field strength sensors are not feasible, data of used transmitters could be got from CMS or Communications (COMMS) system to make an estimation of which areas are not safe. Or a cheap solution could be manual Radiation Hazard (RADHAZ) indicator on entrances to these hazardous areas.

There could be spaces on the ship which are ATmosphères EXplosives (ATEX) spaces or have other similar restrictions only during very specific circumstances. For example when handling some material or refueling onboard equipment. Some limitations for equipment inside those areas could be considered. These limitations could be controlled by IPMS or the IPMS could be used to sense when the atmospheric condition is suitable for explosion and automatically shut down equipment which could possibly ignite the mixture.

Especially in small ships there are situations where it is possible to cause interference to your own systems by using your own transmitters or even interference to other electrical equipment. COMMS and CMS should take care of their own equipment, but usage of ship systems could also be interfered. For example on some vessels the effect of high frequency (HF) transmission can be seen in machinery instruments or heard from PA system, both features are not desired. IPMS could be used to identify and track these kinds of problems. Interfacing IPMS to COMMS or CMS could give the information which transmitters were transmitting when the problem occurred. Open hatches can cause the field strength rise in unexpected spaces but if the IPMS has the hatch monitoring and logging it is not an issue to find isolation to the problem.

Also, sensors connected to the IPMS can be affected by interference. Especially if there are hundreds of sensors all around the ship it can be very difficult to notice these errors. Even if someone is directly observing the value, how can it be known what the reality is. These kinds of errors can be caused by radio transmissions when they happen on specific frequency with specific antenna. Usually the transmission made by naval ships are not long in duration, some can be few seconds while some others change frequency

over 70 000 times in one second. In the worst case these seemingly unknown issues in sensors can hamper crews' trust to the whole system or even aid to make misjudgments of current situation.

4.3.6 Bridge systems

As a disclaimer interviews related to this topic were made with machinery and navigation systems engineers from FDF and with a system expert representing a marine electronics company.

According to the interviews in commercial ships information is usually gathered to the bridge and shown on centralized conning display. Usually in commercial ships this is only for display without any control. Conning display has a direct connection to IAS and it can display current status information and even alarms initialized by IAS. There is not always need for deep integration via data, simple dry contacts can be used to receive alarm information. From the conning display some of the alarms can be acknowledged or cleared with limitations set by the class society rules. Class societies have rules how and where the alarms must be shown, acknowledged and cleared. (Interviews 1 2017.)

According to the representative of the marine electronics company in the products they are supplying there is no limit to how many input/output (I/O) -boards can be added. These I/O-boards can be used to interface sensors or systems to get information and even control other systems. Systems they are providing are highly software based and they can be modified in flexible way. They see that on the bridge there is no need for IPMS displays or control stations. Everything needed can be done from conning display. (Interviews 1 2017.)

In other interviews it was seen that conning displays are only for display purposes without any control and they should probably stay that way. Experiences from integration issues related to bridge systems and IAS have left some skepticism on how well conning display would function in the role of IPMS. In the past these kind of integration issues have left some features completely missing on some ships. (Interviews 3 2017)

One highly critical system which sometimes falls into the gray area between combat systems and bridge systems is the time distribution. Many of the combat or communications systems are depending on very accurate time and may have unforeseen consequences with wrong time. Also if IPMS is to be used for detecting

problems which may have a duration of milliseconds, it is quite impossible to find the right time on the logs without accurate time synchronization. Big problem with time is how to keep it synchronized with other ships. Misaligned time between ships is usually no problem for ship systems but on especially COMMS side it can be critical. Currently quite popular way of getting synchronized time is to use Global Positioning System (GPS) signal to set the clocks. The problem with GPS is that it can be jammed or altered with relatively simple and cheap systems. Global Navigation Satellite System (GNSS) with anti-jam antennas and M-code receivers could be used to improve the situation but still it is important to keep the ships' time correct when signals from satellites are not available. One solution presented by navigation systems expert is to have time servers with highly accurate internal clock in free running mode most of the time. These could be connected to antennas or other time source only during recognized situation. (Interview 6 2019.) IPMS could be used to switch the ship between actively sync to free running mode via integration to the time servers. IPMS could also follow the time difference between the ship's internal time and the time received from external source.

4.4 Survivability

Survivability can be divided into three subcategories. Susceptibility, vulnerability and recoverability. Susceptibility describes how easy it is for the ship to get damaged by environmental, enemy or other factors. Vulnerability tells how well ship can withstand damage, how many zones can be flooded or how well the machinery is separated. Recoverability is more difficult to evaluate because the abilities of the crew are also considered, as well as supporting systems like firefighting or dewatering.

In many ways modern warships are more vulnerable than their WW2 era predecessors. Lack of armor, dependence on sensitive sensors, adoption of commercial equipment and standards together with other cost savings have all increased vulnerability. (Piperakis, 2013.)

Past experiences and survivability analyses have shown multiple enhancements in design rules, including concentrating, separating and duplicating systems, ship separation to semiautonomous zones and damage detectors. (Piperakis, 2013). All of these could possibly be increased with IPMS.

Susceptibility could be increased by making the ship more difficult to detect. Heat from the exhaust or other systems could be cooled. Noise, especially underwater, could be limited with smart control of running equipment or adjusting their settings. Exterior hatches should be monitored to limit increase in radar cross-section (RCS) via open ones. Vulnerability can increase if all hatches are monitored or controlled and precautions are made if enemy engagement is imminent. As stated by Piperatkis (2013) recoverability is the most difficult to model because of crew actions and time decencies. Still increasing recoverability could be done by providing the crew with better situational picture, informative interface for system control, decision support tools like kill cards and automated damage control methods.

According to Piperatkis (2013) there are no single survivability assessment tools taking into account all aspects needed on early stage designs. Changes benefitting survivability like system placement or ship compartmentation can be very difficult to implement at later design stages. (Piperatkis, 2013).

Assessing of survivability values is not a simple task and high level of thought should be put on how to weight the results to provide values suitable for the specific project. Piperatkis (2013) project assessed five combat ships, three different frigates, one corvette and one destroyer. In his work trimaran frigate was the best in vulnerability assessment followed by destroyer and corvette. In recoverability assessment trimaran frigate was once again the best platform while mono hull frigates and the destroyer were close to each other. Susceptibility was best in destroyer followed by the corvette design and trimaran frigate. (Piperatkis, 2013).

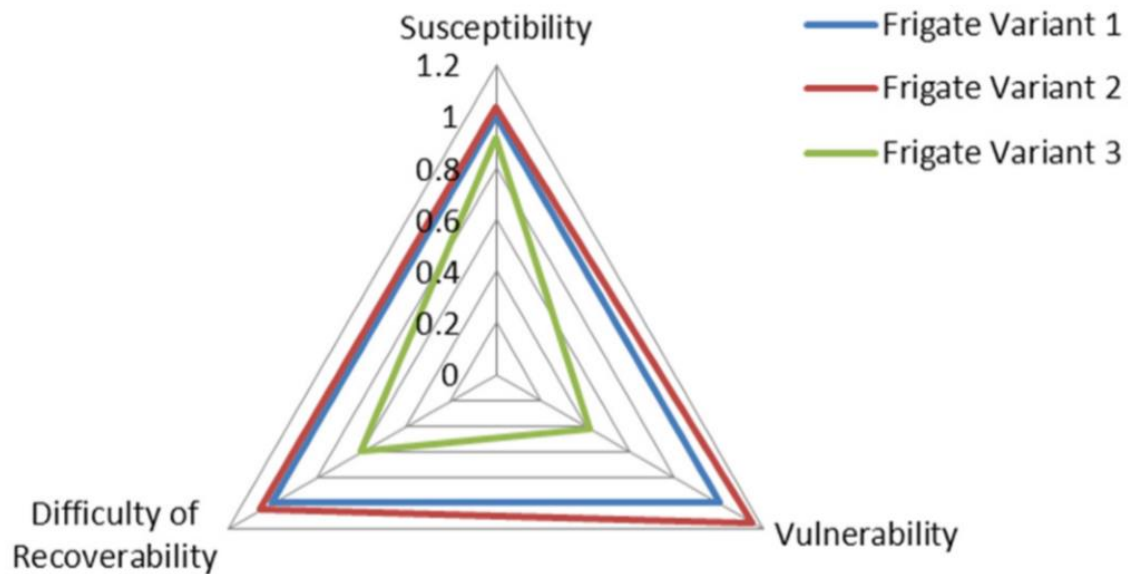


Figure 3, Star Plot of Survivability for the Three Frigate Designs (Piperatkis, 2013). Frigate variant 1 is a baseline typical modern design, Frigate variant 2 is having two passing deck hull and minimal superstructure, Frigate variant 3 is a trimaran design.

When deciding what kind of features IPMS should have similar method could be used as Piperatkis (2013) in his project even if it is difficult to predict what the condition and the capability of the crew are. It could be estimated how the crew will get the information, how they are commanded, which systems the crew should use and how much time it takes to use them. This could reveal some problem points where the IPMS design could concentrate on.

4.4.1 Video surveillance

In the interviews it was seen that different branches on the ship have different expectations from video surveillance. Bridge, Machinery Control Room (MCR), Combat Information Centre (CIC) and security control all need different camera angles. Of course some can be combined and turning cameras can improve the situation. In MCR, IPMS could be used to automatically show video feed from the alarm source with related information overlaid. (Interviews 3, 4 and 5 2017.) If the video system can make analysis on the picture, it could detect abnormal events like smoke, leak, fire or movement taking place and trigger an alarm to the IPMS. If picture recognition is capable enough, it could track where people have been seen and where they have gone to help finding the missing crew. Thermal cameras could also be considered to detect rise or lowering of

heat and to steer the damage control teams to the origin of smoke. In one interview it was stated that experience has proved turning of cameras very important during damage control. (Interviews 3 2017.) To limit switching between different systems like video surveillance control and IPMS the camera control could be integrated to IPMS.

4.4.2 Platform resource coordination

Sensor and weapon resource management has probably been a hot topic since the very early days of naval warfare. The question has been how to effectively use sensors and weapons in different platforms belonging to the same squadron. Which ship of the squadron has the best sensor and most effective weapon for the threat expected or detected. With fast moving targets like missiles or fighter aircraft the roles inside the squadron must be flexible and decisions must be made in short time period. The benefits of this kind of coordination have been described in multiple articles, papers and studies. Johnson and Green (2002) are describing sensor and resource coordination payoffs which can include increased battle space picture accuracy, decreased battle force reaction time and optimized resource usage.

Even if sensors and weapon coordination are a widely discussed topic, I was unable to obtain papers, articles or studies considering platform resource coordination. Simple platform status messages are implemented in some tactical data links like Link 16 or Link 22, but more specific ones seem to be non-existing in tactical level. The idea behind platform status coordination is that if the ship has been in an accident or has sustained damage due to enemy engagement, could then more detailed status benefit other ships in the the same squadron or even command and control stations on land.

During Costa Concordia accident the master did not give information to the company Designated Person Ashore (DPA) about the seriousness of the situation. Even when the master had information that four compartments were flooding and the ship can withstand only flooding of two adjacent main compartments. The master also gave information to Coast Guard Operations Room that the ship was floating and maneuvering when the ship was grounded without propulsion or rudder control. Only after Maritime Rescuer Sub Centre (MRSC) Livorno solicited the “Abandon ship order” was given through the PA system. The situation of the ship was quite clear for the Search and Rescue (SAR) units when the bridge was evacuated but the situation of the onboard passengers and crew was not. (MIT, 2012.)

If the DPA or MRSC would have known the real situation, they could have made the master to call the abandon ship sooner. According to the investigation report (MIT, 2012) if the emergency would have been launched few minutes after the master got the report that three WT compartments were flooded, all passengers could have been evacuated before the ship listed over 30°. The problem in this case was the master who was not giving correct information, so the MRSC did not know the real situation. Direct data connection via satellite, HF or V/UHF from IPMS to shore could provide the necessary information for the on-shore facilities to better evaluate the situation or even run simulations to support the ship crew. Picture from the ship video surveillance system could also benefit finding the passengers, especially if crew has already abandoned the ship. In the Costa Concordia case the ship had a blackout and did not have enough redundancy to keep critical systems running, only internal communications and bridge were working on UPS power. To properly utilize this kind of data connection redundant IPMS installation with its own sensors a backup power is needed. Data connection alone is useless without reliable information gathered from the ship.

On Naval ships similar situations may occur. If the ship is engaged by conventional or Chemical, Biological, Radiological, Nuclear (CBRN) weapons, the crew might not be able to perform or normal communications methods are unavailable even if the ship is still afloat. Naval ships usually have CBRN filters and over pressure system but it may not be enough especially if due to enemy actions there are extra holes on the ship. In these kinds of cases automatic transmission of the ship status could be valuable information for the squadron or other supporting units. Is support needed, when the support must arrive, what kind of support, where the support should be given or is the only task to pick up possible survivors from the sea.

In case of CBRN weapons the ship can be contaminated so that prolonged stay or entering inside is not possible. An ability to monitor the ship systems for safety could be the best option. Of course Emission Control (EMCON) status must be evaluated. If such transmissions are allowed to be made, it should not always be automatic. Strong encryption is also needed to not let the enemy make Battle Damage Assessment (BDA) from this transmission. Probably an Identification, friend or foe (IFF) style integrator and transponder system could be used in conjunction with broadcast in distress mode.

If this concept of remote status is taken even further, also remote control could come into question. Benefits could be limited but technically there should be very little limitations.

Remotely operated aerial or underwater vehicles are quite common these days. Full size naval ship is of course a more demanding and complex machine but it could be done.

Guidelines on operational information for masters in case of flooding in passenger ships are describing shore-based support system with two-way communication link, SOLAS regulation II-1/8-1.3.1.2 (IMO, 2018). It has a good list of needed inputs, calculating methods and outputs, these of course are the same for onboard stability computers. For the two-way communication link there are no guidelines or requirements and this may leave room for subpar implementations.

4.4.3 Hatch monitor and control

Hatch, gate, door or valve status can be very critical in many situations onboard a ship. Changing this status, especially ship wide changes, can always lead to a human error and one hatch, door or valve will be left open. In emergency water, combat gas or other substance may pass through the open hatch and severely affect the survivability of the ship and crew. Monitoring if something is closed or open is trivial with modern technology. But spreading that to the whole ship in every water or gas tight hatch, door and valve, which many be very different from each other, may be a costly task. Even if the hatch is monitored in the event of damaged ship, it could be difficult to monitor if the hatch, door or valve has been damaged and is not functioning anymore. There could be an additional sensor with the status sensor to detect if water is entering through, with gas it might be more difficult due to its more complex behavior.

Controlling of the doors, gates, hatches and valves is a bit more difficult than just monitoring the status. They must be manually operable during equipment malfunctions while the motors or hydraulics must still be strong enough to close them safe way in various situations. Remote controllable valves, hydraulic water tight doors or gates, like stern gates, are nothing new and making them powered should not be an issue. Doors and hatches inside the ship will need more sophisticated solutions, especially if they are remotely controlled from place without direct line of sight. Damage to people or equipment caught during closing or opening should be avoided. Video surveillance system feed from the door or hatch about to be controlled could be automatically shown to avoid these kinds of accidents. Still the closing system on the hatch needs to be strong enough so it could help in situations like on USS Fitzgerald where the crew was unable to close it due to the force of water (Department of the Navy, 2017).

For an IPMS system hatch, door, gate and valve monitoring is an important feature. The status of those opening can greatly affect any given situation. Decision support tools may have real difficulty to work without this information. Controlling could help recoverability during damage control situation especially if some of the controlled openings are in inaccessible space because of damage or flooding. Breach on fire remains has been an issue in multiple cases like HMS Sheffield and USS Stark. (Loss of HMS Sheffield – Board of inquiry, 1982; Department of Defense, 1987). In these cases some time could have been gained with automatically controlled valves.

Depending on the ship design exterior hatch status can greatly affect the RCS of the ship. In emergency it could be useful to increase the RCS while during wartime it should be usually minimized. By having the hatch status on IPMS it could also inform the combat system which side of the ship has now increased RCS.

4.4.4 Heat, ventilation and air conditioning

According to the interviews heating, ventilation, and air conditioning (HVAC) system in current Finnish Navy (FN) ships can be interfaced to IAS but it was seen that no system can ever totally replace manual adjustments on the ventilation. But still integration to IPMS was seen as the future way to go. (Interviews 3, 4 and 5 2017.)

If IPMS is connected to HVAC system and can control it, there might be ways to increase the ships survivability. In some of the damage control cases described in chapter 5, heavy smoke was the major issue affecting visibility and making damage control activities a lot more difficult. With the help of HVAC system capabilities IPMS could limit the ventilation in spaces where it is not currently needed and use that performance to help with smoke clearing. Also fire could be slowed down by limiting the air it can have. If fire is detected, all ventilation to that space could be stopped and hatches closed. Or if the space is unmanned, tightly sealed and HVAC system has the power, could vacuum be used to put out or slow the fire?

In one interview it was discussed if HVAC system is damaged and its performance limited. Could IPMS try to prioritize between crew and different equipment which require ventilation most or what is the best way to increase survivability on current situation? For example in hostile situations it might be best for the ship to keep combat system and machinery cool, while the crew can sweat a bit. (Interviews 3 2017.)

In HMS Queen Elizabeth the IPMS is including kill cards. Some actions can be initiated from the kill cards displayed by the IPMS. Some kill cards can automatically take actions, like stopping ventilation when fire is detected without the need of user input. (Davies & Jewell, 2015)

In interviews it was stated that over pressure system protecting against CBRN weapons should also be monitored by IPMS. Air quality should be monitored after the filters and if a problem occurs alert should be raised and the problematic unit immediately stopped. This would limit the risk of getting unwanted gases inside the ship through damaged or faulty filtering. Also, according to the interviews if one CBRN filtration unit goes down, others must work as backup. The status and control of hatches and valves is also critical to succeed in over pressure and to avoid contamination. (Interviews 3 and 4 2017.)

In the interviews also oxygen and carbon monoxide level were seen as important features. In current ships oxygen level monitoring has been connected to fire alarm system but sometimes there have been issues with this integration. It was seen that IPMS should have monitoring capability for each room and possible alarms should be given first to the room, not the whole ship. (Interviews 3 and 4 2017.)

4.4.5 Stability calculation

According to the interviews stability calculations made by stability computer should in future ships be readily available. Stability situation should be available in the damage control centers and consoles. Currently all Finnish Navy ships have instructions on paper of what to do in a few specific situations. In the interviews it was seen that software should be used to calculate each situation in real time and give recommendations for what to do. This feature will not take too long or add any real value. (Interviews 2, 3 and 5 2017.)

In interviews it was also seen that ice accretion should be monitored. Monitoring by sensors or calculated from ship movements was proposed in interviews. (Interviews 3 2017.) Maybe also video surveillance system could be used to estimate the ice build-up optically. Helicopter deck could be heated to limit the ice build-up and to make it safer for helicopter operations. (Interviews 3 2017.)

According to the interviews currently installed onboard stability computers need manual input of the amount of flooding or water used for firefighting. In current solutions only

tanks are measured and even that can sometimes have problems. When the ship is level IAS and has onboard stability computer, which both have their own sensors, they are usually very well aligned on the tank status. In other than completely level situations there can be a slight difference of the measured values. This might be due to sensor calibration or just different type of sensors behaving differently. Currently there are no sensors to automatically measure the cargo situation. Laying mines, dropping depth charges, shooting missiles, using guns or helicopter place on board must be manually input into the stability computer if it is seen necessary. In the interviews this was seen as easily predicted task and it is simple to input this data to the stability computer. (Interviews 2 2017.)

In the future, flooding sensors should feed information to stability computer. In the interviews it was seen that status of water tight hatches, vents and doors must be monitored and the system should give alarms if they are open. The most critical hatches should also be controlled. In the interviews it came up that during emergency most of the crew effort can go to stopping the flooding, putting out the fire or other damage control actions. Experienced crews have a good feeling about the stability of the ship but it could still be helpful if the stability computer could automatically display current situation and show how it is proceeding. If the flooding cannot be stopped right away or fire control needs excessive amount of water, it should be calculated if the dewatering systems are still operational and have enough capacity. IPMS or stability computer could give recommendation for the ship's trim or list of how to set the tanks if they are functional. One interviewed system expert saw that all stability related estimations or decision supporting information are very difficult to calculate accurately in real world with different sea conditions. It was also discussed that no ship is sailing with stability computer. Stability computer is a good tool to aid but in the end the commanding officer has the responsibility. The crew must have a gut feeling of the ship. (Interviews 2, 3 and 5 2017.) Direct translation of Finnish to English quotation from the interview 2,

“Reality always differs from calculations and you can never achieve the accuracy of a single kilo or even tonnes”.

This previous quotation leads us to Costa Concordia accident report where it was found that the simulation software used after the accident underestimated the heeling to be 6° less than in reality. Accident report also states that the stability computer was unable to monitor flooding, control equipment or make estimations based on breach size or

flooding time. Recommendations on that report include installation of stability computer with connection flooding detectors. (MIT, 2012.)

On HMS Queen Elizabeth class aircraft carriers IPMS is getting information from multiple sources like from tank fluid level sensors, aircraft weight and position, damage and flood information. This makes it possible to display real time stability information on the IPMS control stations. (Davies & Jewell, 2015)

If the ship has received damage, battle or other, it might be difficult to assess which spaces are still watertight. This will greatly affect predictions on what will happen when the flooding progresses. Maybe HVAC system could be utilized to measure “tightness” of the spaces and cross reference with historical intact data.

4.4.6 Noise

From specifications sheets, like the Wärtsilä 20DF product guide, it can be estimated what noise and vibration levels the units are producing. For example the Wärtsilä 8L20DF is producing air borne noise level of 118 dBA when at full load and nominal speed. Sound power is depending a bit on the frequency. (Wärtsilä, 2018) The total acoustic signature of the vessel can be difficult or impossible to predict accurately but it can be measured. A simple list of systems which can be used when silence is needed can be formed. But if more flexibility is needed, system like the IPMS should know or measure live the noise level and frequency caused by each component. Based on that information IPMS could control machinery within the given noise limit. Not just shutting down pre planned equipment but using the flexible way that is needed while keeping noise below the limit required by current operation. Also if the noise signature can be altered, IPMS can make it more difficult for the enemy to form proper identification libraries or to make correct identification. Something could be done even if it might be impossible to make modern warship sound like Fiskari with Yanmar YSM8 single cylinder diesel engine.

Noise measurement could also benefit maintenance and system condition monitoring. Even if according to Dikis et.al. (2014) vibration measurement is the most typical way of doing this, sound could also be used to find problems. Especially in moving machinery where permanent vibration sensors are impossible to implement. Big changes in sound

spectrum compared to when the ship was delivered may indicate faults and may even lower the susceptibility and that way affect the total survivability of the ship.

4.4.7 Fire alarm

In the interviews it was seen that fire alarm system and IPMS should be integrated. Especially if IPMS can control hatch, valves and the HVAC system. According to the interviews many of the currently installed fire alarm systems cannot display visually where the fire is located. Only the sensor number may be told by the system and then it is needed to be checked elsewhere where that sensor is located. If the crew on watch is following the IPMS display, the most relevant information for each alarm should be displayed automatically. Start of the damage control would be faster if space where the alarm has been triggered is clearly displayed in a ship GA drawing or similar. Together with this map display status of affecting hatches, status of ventilation and temperature of the space should be seen. (Interviews 3, 4 and 5 2017.)

According to the interviews all rooms shall be temperature monitored and smoke density monitored. Also, IPMS system could add more automation to fire control. For example if the fire starts at the bow engine room, the system could automatically move all power generation to the aft engine room and close ventilation. Still it was seen that some actions must be manual, like filling ammunition magazines with water. Requirements for the sensors must be considered if they need to withstand heat or work after being submerged. (Interviews 3, 4 and 5 2017.) According to Zatrain (2010) on USS Stark where the temperature of the fire was around 1700 °C, it might be difficult to have sensors and cabling which can withstand all possible situations.

In incidents like USS Stark or HMS Sheffield thick smoke made it very difficult to find the source of fire. Augmented reality helmets with thermal cameras could make working in smoke more efficient. These helmets could receive real time updates from the IPMS to show real time sensor data. On both USS Stark and HMS Sheffield firemain were also breached. If temporary firemain route is needed, IPMS could show where it needs to be routed and connected.

On USS Stark so much water was used for firefighting that it started to affect stability. In the interviews it was also seen that the amount of water or foam or other firefighting

material used could be an interesting value for the stability computer. It could also be calculated what the ratio between dewatering and adding water is.

4.4.8 Cyber security

Cyber security has been a hot topic for a long time now. Still sometimes it feels that it is not taken very seriously unless you have systems which are connected to the Internet. Ship internal systems may fall to false sense of security when they are standalone systems. With the increase of Transmission Control Protocol / Internet Protocol (TCP/IP) based networking, COTS hardware and operating systems the environment becomes very similar to everything else, like the Information Technology (IT) infrastructure of businesses or personal computers at homes. This makes attacks like malware able to infect ship systems even if it was not originally designed for ships. According to Baltic and International Maritime Council (BIMCO) sometimes intrusions can go undetected for years. On one incident a power management system which could be connected to Internet for diagnostics and updates had dormant worm waiting for this connection. It was believed that a visiting technician infected the system with Universal Serial Bus (USB) device. The worm had been in the system for over 2 years before it was detected. (BIMCO, 2018.)

There are a few different guidelines or recommendations available for handling cyber security on ships. BIMCO “The Guidelines on Cyber Security Onboard Ships” and DNV-GL “Cyber security resilience management for ships and mobile offshore units in operation” both documents have similar idea of addressing the cyber security issue by evaluating the risks first. This process should include finding out the threats, how they are prevented, what happens if an attack is successful and how it can be recovered from the attack. These documents are of course made mainly for commercial ships but most of it is applicable for naval ships also. (DNV-GL, 2016; BIMCO, 2018.)

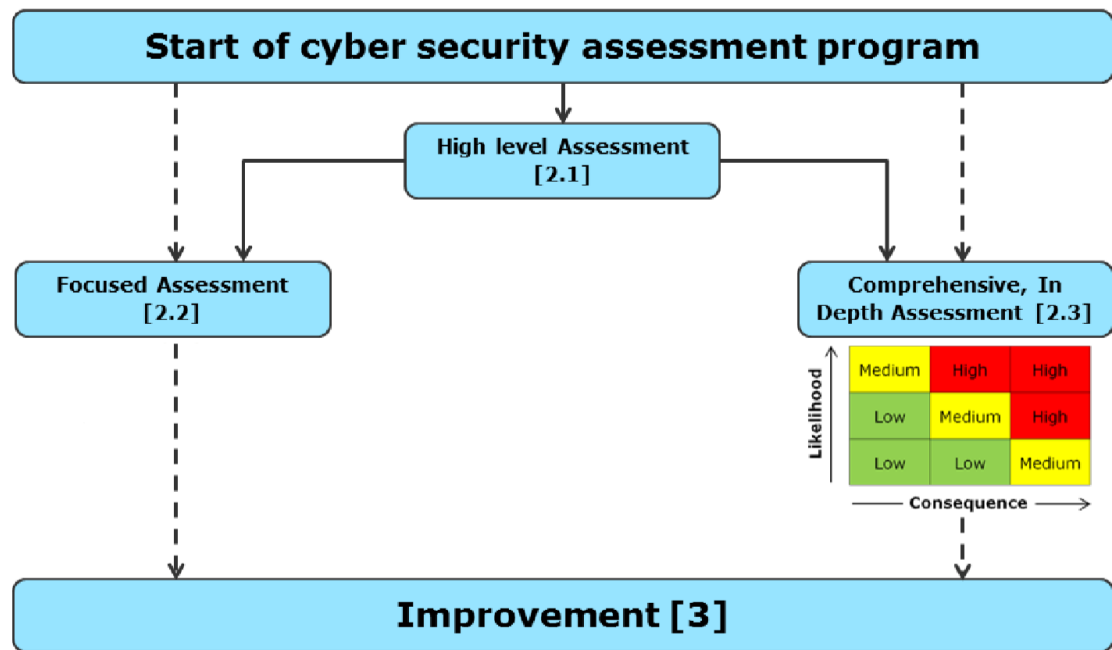


Figure 4, Cyber security assessment sequence (DNV-GL, 2015)

DN-GL and BIMCO documents both have different kinds of platform management systems included in their possible vulnerable systems lists. An IPMS should also be evaluated thoroughly as it falls clearly into this category. IPMS could be one main target for cyber-attack, it is centralized system where access to multiple different systems can be achieved. Or the IPMS could be used to take control of some critical features at crucial time. The IPMS should not be connected to Internet. Even if Virtual Private Network (VPN) tunnel or similar encryption method is used, it must be considered what is the risk of someone taking control of it are.

For this thesis very light open source surface scratches to two possible targets for cyber-attack were considered, diesel engine and stability computer. These may or may not be main targets, but these were selected as examples.

In normal situation cyber-attack to stability computer could have a slight effect to the mission of the ship. If the chief engineer has any clue what he is doing, there is very little risk even if the stability computer must be shutdown. (Interviews 2 2019.) On current ships effects are also limited because of the standalone arrangements. But if the stability computer would be integrated to IPMS and the IPMS would have the rights to automatically start actions to restore stability, in this case attack to stability computer could have more impact. These effects could be limited with redundancy or by having

backup storage drive for the stability computer or even a full backup computer detached from network when not needed. Also, some of the sensors used by the stability computer should be doubled up with sensors connected straight to IPMS for reference. Data or status information in the stability computer could be more interesting for the enemy. Especially when conventional engagement happens beyond the line of sight it can be difficult to assess the weapon effectiveness. Huge cloud of smoke could give some information but it can also be used for misleading purposes. But if data from stability computer could be sent off the ship, it could provide valuable information for BDA.

Diesel engines have multiple ways they can fail or be made to fail, only few are touched here.

In diesel engines thermal shock or fatigue from repeated thermal shocks can cause the cylinder liner to crack. (Bocchetti et.al. 2009.) Fonte et.al. (2015) are listing some root causes of marine diesel engines failures. This list includes loss of lubrication, over speeding of engines and engine power imbalance caused by incorrect monitoring. Most subtle attacks could be directed towards parts which are known to fail most frequently. On chart presented by Perakis et.al. (1990) fuel oil injection system was found to be the most common reason of failure on marine diesel engines (Banks et.al., 2001). An attack causing problems to known failure points could stay unnoticed for a long period of time and no engine type or ship class wide investigation would start immediately.

If the attack must be accurately timed and not based on long term fatigue damage happening at random time, more rapid failure modes must be considered. Engine status monitoring could have additional redundancy from standalone sensors or gauges to limit the risk of single sensor showing wrong values. But if the failure process is fast enough it could be a difficult task for the crew to notice this difference and take action before the failure happens. For example in case of Wärtsilä W20DF if the UNIC C3 system is compromised the attacker could potentially stop the lubrication system or cause cylinder over pressure, or just give wrong information to the ESM module. This will normally lead to alerts on the IAS and cause immediate shutdown of the engines (Wärtsilä, 2018). In combat situation this could leave the ship into a very vulnerable state, conventional attacks could now have higher chance of success to inflict more permanent damage. If more permanent damage is needed without usage of traditional weapons, also the monitoring features of MCM and ESM modules of the Wärtsilä W20DF UNIC C3 system should be put to state where it is not showing real values or giving alarms and only the eventual engine failure would alert the crew (Wärtsilä, 2018).

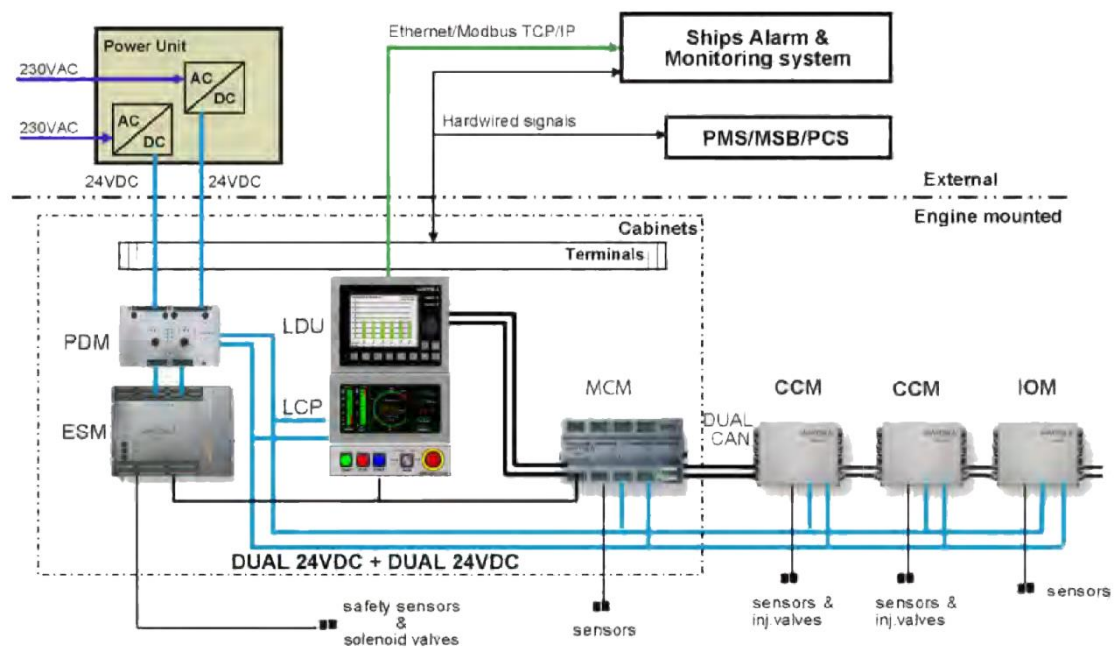


Figure 5, Wärtsilä UNIC C3 engine control system architecture for diesel engines (Wärtsilä, 2018)

IPMS could provide an additional layer of protection by introducing its own sensors and shutdown method to the engines. This would increase the difficulty of successful cyber-attack if two or more completely different systems must be affected at the same time. If latencies are kept on the level of HMS Queen Elizabeth class IPMS, the system could have a chance to react before permanent damage will happen.

If one would put the tin foil hat tightly on the head and read through the USS Fitzgerald, USS McCain and HNoMS Helge Ingstad incident reports, the question could rise whether the navigation systems have been compromised so that when surface track is observed to be in collision course it will be hidden from the screens? According to BIMCO (2018) Electronic Chart Display and Information System (ECDIS) systems have had few known incidents. This is probably not the case in these two but it could be vicious way of trying to sink ships during peace time.

4.5 Testing of the system

Even if standards like Allied Quality Assurance Publications (AQAP) 2110 which expect high level of risk management and documentation are followed still in the end, only testing the system will prove the final status. In multi contract situations it may not be

easy to detect the responsibilities who will plan and execute the testing, or who is responsible if the test fails. AQAP 2131 gives a simple answer to testing, all testing and inspections to demonstrate the system shall be performed by the system supplier. Buyer's responsibilities may not be released with this, especially if information, equipment or other assets are provided by the buyer or third party.

First risk for this kind of system which interconnects to multiple systems provided by other supplies should be the interfaces. Who will provide the interface control documentation (ICD) and who will adapt to it? Can the ICD be fixed or is the development still ongoing? Who is responsible for the testing and when? To mitigate these risks proper interface testing should happen as soon as possible from the start of the project. Not only the official acceptance tests but also testing during development to catch errors in documentation, physical interfaces or bugs in software.

Usage of middleware standards like Data Distribution Service (DDS) or Common Object Request Broker Architecture (CORBA) could mitigate some risks of the integration. Usage of these is recommended by US Navy's Open Architecture Computing Environment for defense systems (Eryigit & Uyar, 2008).

During contract negotiations testing should be considered carefully. Two simple solution to lower the risk of problems in interfaces could be to make the IPMS supplier provide interface test tools to other system provider, or vice versa. If adequate simulators or interface devices are delivered to IPMS supplier, it could greatly benefit the IPMS factory acceptance test (FAT). A sensor which are read by simple analog to digital converter (ADC) can be easily simulated but if something more complex like proprietary or even standard bus interface is used it is more demanding and should be tested as early as possible in the project.

Interface simulators or real interface equipment are a good option whenever possible. Without them testing during development and in FAT could be very difficult. In any case, if real test with interfaces to ship systems is taking place in Setting to Work (STW) or Harbour Acceptance Test (HAT) phase, major delays are to be expected. According to Davies & Jewell (2015) on the HMS Queen Elizabeth class program hardware from the second ship was used on shore integration facility (SIF) to mitigate the risk of integration problems and to make STW go fluently. Early integration was also endorsed in interface testing with the OEM support at the SIF or at OEM's site. Flaws were found on almost all the interfaces tested in the early integration tests. (McKelvie & Lakey, 2018)

During design phase displayed units and proper values are to be defined. Simple things like temperature measurements may cause confusion. If usage of *Système international d'unités* (SI) units is required, should the temperature readings be in kelvins or degrees Celsius? What happens when sensor readings are off the scale or what happens when sensor reading is not available, is 0 and N/A same or different thing? In the end the system must be logical, easy to use, but still informative. All these things come more important when the crew is fatigued, stressed or when ship is used in hostile and probably life threatening situations. If the crew is expected to trust the IPMS and make decisions from the information, it requires that it must be tested to adequate level.

On HMS Queen Elisabeth program HMS Albion is used as trial platform for some features (Davies & Jewell, 2015). As stated by McKelvie & Lakey (2018) the best feedback for the system design was received from the watchkeepers who use system daily. It was also observed unsurprisingly that harbor test did not tell the whole truth. After the sea trials more than 17 000 changes were made to alarms and warnings which behaved differently in the sea than in harbor. (McKelvie & Lakey, 2018.) The importance of proper sea acceptance test (SAT) is often overlooked on systems which should not be affected by the movement of the ship. Especially naval ships with complex electromagnetic environments (EME) relying only on HAT can be a costly decision.

5 COULD INTEGRATED PLATFORM MANAGEMENT SYSTEM AFFECT THE OUTCOME

5.1 USS Fitzgerald collision with ACX Crystal

USS Fitzgerald is an Arleigh Burke Class destroyer which collided with container ship ACX Crystal on 17th of June 2017. Both ships were sailing at straight line for the past 30 minutes before the collision. Neither of the ships took any action to avoid the contact until one minute before the collision when it was already too late. Port side of ACX Crystals bow hit the starboard side of USS Fitzgerald. Bulbous bow of the container ship penetrated to the starboard access trunk of the USS Fitzgerald. (Department of the Navy, 2017.)



Figure 6, Starboard side damage to USS Fitzgerald, (Department of the Navy, 2017.)

USS Fitzgerald was in material condition “modified ZEBRA”, Water tight doors and hatches were closed but scuttles on the hatches were open. 18 spaces were flooded due to the hole below waterline and there were no water tight doors or fixtures between them. 13 spaces were flooded due to water tight barriers not being closed on time. 13 spaces were partially flooded due to ruptures in firemain and Aqueous Film-Forming Foam (AFFF) lines. Seven sailors were perished. (Department of the Navy, 2017.)

In US Navy three different material conditions are specified. Condition X-RAY is used when there is no danger or e.g. when ship is at home base during normal working hours. During this time only doors and hatches labeled with black X should be kept closed. When the ship is at sea condition YOKE is set and all doors with black X or black Y are to be closed. During wartime or when in general quarters, condition ZEBRA is set. On condition ZEBRA all hatches and door with black X, black Y or red Z need to be closed. (Department of the Navy, 2019; Bureau of Naval Personnel, 1970.)



Picture 1, Hatch with scuttle, marked with Z. (Department of the Navy, 2017.)

Ship material condition “modified ZEBRA” and late call for general quarters were probably the main cause of flooding to some very critical spaces like combat system equipment room, radio center, radio transmitter room, sonar rooms and main engine

room 1. The idea behind this “modified ZEBRA” is to allow easier access through the ship but still have the ability for faster transition to ZEBRA, compared to the time it takes to transform from YOKE to ZEBRA. On the other hand, if the ship material condition had been YOKE, maybe even more spaces had been flooded. On combat situation the ship should have been on condition ZEBRA but if not flooding in these critical spaces could have left the ship and its crew to the mercy of the enemy or at least the ship would have limited combat capabilities.

From open sources it is not completely clear if Arleigh Burke -class destroyers have an IPMS system or not, and if they have, what kind of system it is. If there is no such system or the system is not capable of monitoring flooding or doors and hatches. This kind of features could benefit in cases like the collision between USS Fitzgerald and ACX Crystal. With flooding and hatch monitoring the crew would immediately see which hatches need to be closed if they are open.

All seven sailors who perished were located in berthing 2. Some of them were sleeping during and even after the collision. Complete flooding was estimated to be happening only in 30 – 60 seconds and floating debris made it difficult to escape. (Department of the Navy, 2017) Flooding this fast would greatly limit any complex crew actions to control the flooding. If anything could be done, it should happen almost immediately. For a system like IPMS to have any chance of saving the crew members automatically it should know where the crew is located, how fast the flooding is, where the main source of flooding is, current stability situation, status of tanks, weather conditions, ship position, map, tactical picture, status of dewatering systems, hatch/door/valve control and operational situation (normal or hostile). From this information the system could estimate if the speed of water rising in spaces with crew could be delayed by letting water intentionally pass through watertight doors and hatches or by adjusting the ship pitch and roll. To make this decision the system would need to know where the water will end up, will it affect critically the stability, is the ship still recoverable after the crew is evacuated, which systems are at risk and if it is suitable for the situation that these systems are going to be offline. Platform status coordination (chapter 4.4.2) between ships could also aid in these situations. IPMS could calculate if ships' own systems are unable to handle the situation or do their own units nearby have useful capabilities. Assistant request with instructions could be sent in advance to the ship coming to support. According to the collision report of USS Fitzgerald this would have been difficult because external communication was lost (Department of the Navy, 2017).

5.2 USS McCain collision with Alnic MC

USS McCain is an Arleigh Burke Class Destroyer which collided with Oil/Chemical Tanker Alnic MC on 21st of August 2017. USS McCain was in transit towards Changi Naval Base, Singapore. The Helmsman had difficulties in keeping course while adjusting propulsion at the same time. Commanding officer noticed this and ordered dividing of the rudder and propulsion controls between Helmsman and Lee Helm station. Propulsion control was supposed to be transferred but by mistake the rudder control was transferred to Lee Helm. Helmsman was unaware of this and observed the loss of steering from its station. Making situation more confusing the Helmsman had rudder at 1-4-degree angle and when the control was transferred to Lee Helm station it had a setting of 0 degrees. This made the ship deviate from its course to port. CO ordered the speed to be lowered from 20 knots to 10 knots. Lee Helm reduced the throttle but it had taken control of only the port side shaft. Split plant propulsion operation where the gas turbines drive shafts independently was selected 3 hour earlier. Starboard shaft speed remained and turn to port increased. Backup manual steering was taken in control on the aft steering station, only 15 seconds later steering was taken by Helmsman and again after 11 seconds it was back at aft steering station. Meanwhile propulsion control was matched, and the ship was slowed to 5 knots, but it was still turning to port. 15-degree rudder to starboard was ordered and after that USS McCain was on steady course. 14 seconds later bulbous bow of tanker Alnic MC hit USS McCain below the water line. (Department of the Navy, 2017.)



Picture 2, Damage on the USS McCain (Department of the Navy, 2017.)

Material condition on USS McCain was “modified ZEBRA”. These material conditions are described in previous chapter of the thesis. Point of impact for the collision was at the port side in the location of berthing 5 and 3. Only two of the 12 sailors in berthing 5 were able to escape. It is estimated that berthing 5 was completely flooded in just 60 seconds. On berthing 3 most of the 71 sailors assigned there were able to escape. Some got trapped but were rescued later. (Department of the Navy, 2017.)

In many ways USS McCain and USS Fitzgerald casualties are quite similar. Collision with object under the waterline allowing fast flooding of berthings, trapping crew inside. Some of the IPMS features suggested for USS Fitzgerald could apply for USS McCain case also. But in the USS McCain case maybe something could be done to the propulsion and rudder control also. Most of the issues leading to the collision maybe related to training or crew errors. User interface style which is common across all systems would greatly increase the ease of usability and less training or experience is needed to master them. Especially if crews are used on multiple different classes of ships. Also, a good source of ideas could be airplanes and their fly-by-wire systems. The user should tell the system on higher level what the ship should do, and the ship would perform necessary actions with its machinery. Of course several different kind of

autopilot systems are available but for some reason it seems that they are not always trusted.

5.3 HMS Sheffield sinking

HMS Sheffield was a Type 42 Destroyer of the Royal Navy. She was part of a task group operating in the total exclusion zone near the Falkland Islands during the Falkland war. On May 4th, 1982 she was attacked by two Argentine Navy Super Étendard strike-fighters, armed with Exocet anti-ship-missiles. Two missiles were launched against the HMS Sheffield, one missed but one managed to impact. (Loss of HMS Sheffield – Board of inquiry, 1982.)



Picture 3, HMS Sheffield after it was hit by an Exocet missile (The Guardian, 2017)

Hit was received on deck 2 starboard side between the Forward Auxiliary Machinery Room, Galley and Forward Engine Room. The missile hit caused 4,5 m by 1,2 m hole on the side of the ship. Explosion of the missile also caused widespread minor shock damage and large fires broke out. Acrid black smoke rapidly spread across the ship and this quickly forced the evacuation of several key rooms. The source of this smoke was burning diesel oil and missile propellant. Crew was unable to clear the smoke in the forward section and only partially successful in the aft. Damage control efforts after the

impact were uncoordinated, no emergency Headquarters (HQ) 1 was established, it was not clear which quarters had been abandoned and where the command of the ship was located. (Loss of HMS Sheffield – Board of inquiry, 1982.)

HMS Sheffield had four fire pumps from which only one was able to run for a while. Fire mains had been breached at impact and the pressure was never gained. Without the fire mains there was no real chance to fight the fires with portable pump and buckets. Fires spread quickly and not any attempt to fight them was successful. HMS Arrow and HMS Yarmouth were able to provide assistance albeit they frequently received submarine and torpedo alarms. After four hours of fighting the fire the captain of the HMS Sheffield ordered abandon ship. He was convinced the ship's fighting capability was destroyed and it was too risky to keep HMS Arrow and HMS Yarmouth vulnerable to enemy attacks. HMS Sheffield continued to burn for four days until during tow it sunk due to water ingress through the impact hole in bad weather. (Loss of HMS Sheffield – Board of inquiry, 1982.)

There are multiple reasons why the HMS Sheffield was hit and eventually sunk. The base for most of them is human error but also limitations in the combat systems could be blamed. What happened after the hit is also a combination of the ship's and crew's limitations. It might be a bit harsh to say crew limitations because exceptional bravery was also seen when the crew was trying to save the ship and keep its ability to fight. Crew limitations in this case are more related to human's inability to work in thick smoke and high temperatures.

So, what could imaginary IPMS do if it would have been installed onboard HMS Sheffield in 1982. According to the accident report and newspaper articles the personnel on the bridge did nothing when the missile was detected even though the operating procedure called turning the ship towards the incoming missile. When the raid was observed on the HMS Glasgow it was released to tactical datalink, LINK 10. (The Guardian, 2017, Loss of HMS Sheffield – Board of inquiry, 1982.) If HMS Sheffield would have received the hostile tracks the information could have been forwarded to IPMS for immediate change of heading. This could have been semi-automatic or even fully automatic action taken by the system.

After the hit there was a lot of smoke which blocked access to certain areas. (Department of defense, 1987) HMS Sheffield's HVAC systems are unknown but maybe with intelligent automation of ventilation and hatch control the smoke spread could have been controlled and the clearance could have been more successful.

If firemain could have been isolated by automatic valves in high resolution, some pressure may have been able to be formed. Of course if the pumps are not running, not much can be done. USS Stark guided missile frigate got hit by two similar kind of Exocet anti-ship missiles as HMS Sheffield. Also, on USS Stark firemain was breached but by isolating the leak it was possible to gain pressure and eventually the fires were put out.

Situational awareness and commanding could be increased by IPMS or damage control system displays providing information of temperatures, hatch status, location of personnel and status of the ship. Now valuable time was lost because of the uncoordinated start of damage control activities.

5.4 HNoMS Helge Ingstad and Sola TS collision

Only Preliminary report (aibn & daibn, 2018) and part one of the collision report (aibn & daibn, 2019) between Norwegian Fridtjof Nansen-class frigate HNoMS Helge Instad and tanker Sola TS is available. Part two with more information about what happened after the collision is not available and no date of release has been given by December 2019.

The accident happened mainly because of human errors, no system malfunction has been blamed (aibn & daibn, 2019). From IPMS stand point not much could have been done to prevent the accident, at least according to the information available today. Maybe if the bridge design had been different or augmented reality systems were used the human errors and the followed accident could have been avoided.



Picture 4, Sola TS observed from HNoMS Roald Admundsen during test. (aibn & daibn, 2019)

For this thesis the interesting part is that HNoMS Helge Ingstad had an IPMS. There were several IPMS consoles from which one console was located on the bridge. When the system was updated in 2017 it was possible to update two IPMS consoles while the rest were running the old version, this would indicate high level of redundancy in the design. According to the Norwegian Armed Forces (Forsvaret, 2019) the IPMS logs could be collected from the hard drive on the bridge. Navigation system is integrated to the IPMS via Distribution of Navigation signals (DINA) system. From the IPMS recordings information, like requested and actual rudder angle at given time, can be read. IPMS was updated in 2017 to include features like dynamic kill cards, playback mode, electric distribution monitoring, 3D view of equipment and 360° view of compartments. IPMS can monitor and control various systems onboard the HNoMS Helge Ingstad. (aibn & daibn, 2018, 2019, Galaxia Militar, 2017.)

After the collision with Sola TS flooding occurred in three watertight compartments. All propulsion and rudder control were lost and the ship uncontrollably grounded at the

nearby shore. According to the accident reports the crew used stability documents but not stability computer or IPMS to assess the current stability status. The conclusion was that the ship could kept afloat but it is having “poor stability” status. It seems that in the aft compartment there was no flooding measurement or there was a malfunction in the system because there was uncertainty if it was also flooding or not. The stability status of the ship would change to “vessel lost” if more compartments than the previously observed two are found to be flooded. (aibn & daibn, 2018; aibn & daibn, 2019.)

Eventually via the hollow propeller shafts water could pass from aft generator room to gear room and from gear room via stuffing boxes to aft and fore engine rooms. Evacuation was prepared when this more substantial flooding was found out. Eventually the ship sank at the site where it grounded. (aibn & daibn, 2018; aibn & daibn, 2019.)

6 CONCLUSIONS

The conclusion of this thesis is that there are unlimited number of features what a system like IPMS could have. Opinions concerning what features IPMS should have can vary depending on who is asked. Some of these variations can be explained by not knowing what is possible or if the current practice has been good enough. Some are due to restricted experiences from IPMS usage in real operations, some are related to the need to keep things as simple as possible. Some persons may have commercial interests steering their opinions. It was no a surprise that typically during the interviews there was at first some reservation towards the concept of IPMS. What is the point, can it break my system and is such a system really needed? All those questions are valid and some of them are answered on this work.

6.1 Summary

To answer the question if better integration of systems can be the answer to lean manning or survivability requirements. The answer is yes on both, it can be one part of the solution. Performance of many currently installed systems could be better if they would get information from other systems or sensors. It can be quite easily estimated what can be done with this additional information but it is more difficult to predict how that would affect the performance or survivability of the ship in real life. It is easy to say that crew actions have a huge impact on survivability of the ship. And making the crews life easier especially in difficult situations the same tasks could be accomplished better with less crew. Less people sitting in front of monitors will release personnel to other damage control activities. Even if it is difficult to estimate crew performance in different situations, one thing sure is that better and more usable situational picture will increase crew performance. The good thing with better situational awareness is that it helps in all situations, not only when survivability is measured. Depending on what the current level is big gains could be seen in this area with carefully designed IPMS solution.

What size of ships should consider IPMS? The conclusion from this work is that there is no limit either way. Even if it is not necessary to control or even monitor multiple and complex systems, it can help if the user interface is similar across all vessels in the fleet. Especially when personnel is used in multiple different class of ships, accident like the

one on USS McCain could be avoided or at least the risk could be lowered with familiar user interface.

What features should IPMS have is of course highly dependent on what kind of ship is in question, where it is used and what is its role. With unlimited funding all possible features with high level automation could be considered. Sometimes actually simpler solution might be better or at least more user friendly. If the ship in question is one of 50, where many are in reserve, operational area is calm and enemy is inferior in all areas of warfare, less effort could be focused to survivability aspects and more focus on ease of use and life cycle costs. In the other end when the ship in question is one of few, operational area has tensions and the enemy can match or even have the upper hand in some areas of warfare, most of the effort could be put on features increasing survivability. Of course, life is not that simple, and the final solution is always a compromise. Many of the features or systems addressed in this thesis are linked together. For example hatch, door, gate and valve control or status could be required by firefighting systems, stability computer, CMS, damage control console, hatch control system and HVAC systems. While for example firefighting system should give information to stability computer, hatch control and HVAC systems. Integration without IPMS could be done but the result could be too complex to be usable and cause difficulties for procurement with multiple development contracts and ICD's to handle.

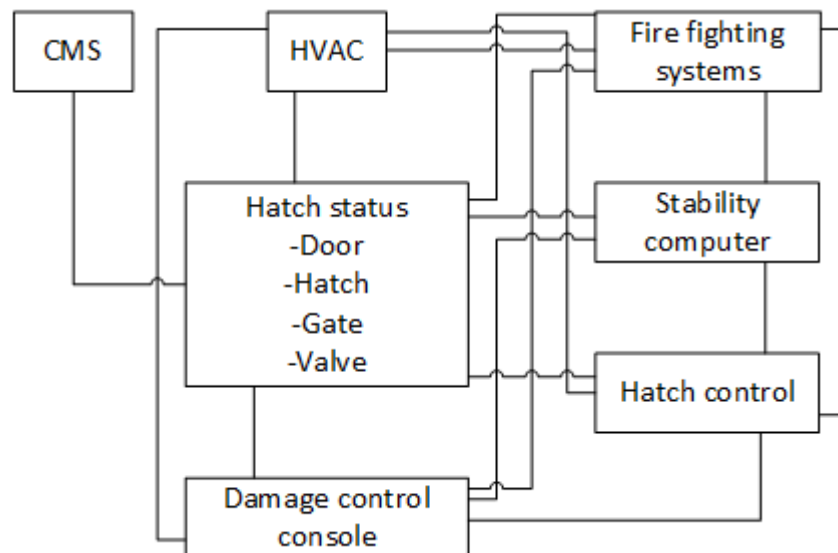


Figure 7, integration overview without IPMS

If IPMS is used the overview of the systems can be a lot simpler and usage of the system, simpler.

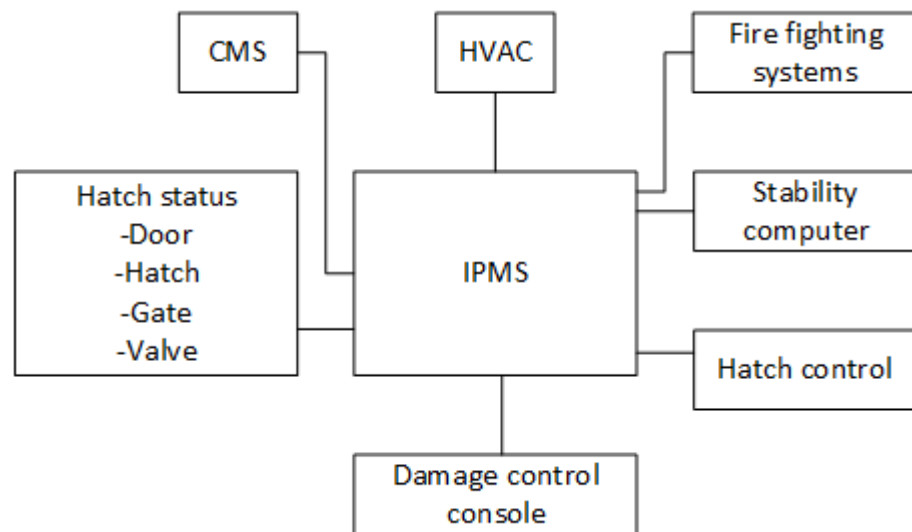


Figure 8, integration overview with IPMS

Situational awareness in all operations is crucial. In a complex ship with multiple subsystems it can be quite difficult to form quickly. If each subsystem has its own operator, they can keep track what is happening with their systems. But if someone must command what to do next, having all the information available in user friendly matter can make the difference. To ease the workload of the operator some task could be automated completely. With automation faster response to unexpected situations could help the ship and its crew to survive. Currently all known IPMS solutions are made by humans and they all have and will have errors. They can also fail like any other system onboard. It must be carefully evaluated how much control can be given to IPMS and how important the IPMS is for the ship. This evaluation will give answers to what level of redundancy is needed, how it will be protected against environment or threats like cyber-attack and should the existence or at least most of the details of such system be kept secret to avoid it being targeted.

Operational performance in the picture on next page means how well all capabilities of the ship can and will be used. If some features are hidden in the depth of Keyboard Video Mouse (KVM) matrixes and different GUIs which are not used often, they can get underutilized or even forgotten when they are needed in real situation. This is where even the most lightly featured IPMS could help. Giving the operators a single style of

GUI with most used features, it could ease the workload and decrease decision making time.

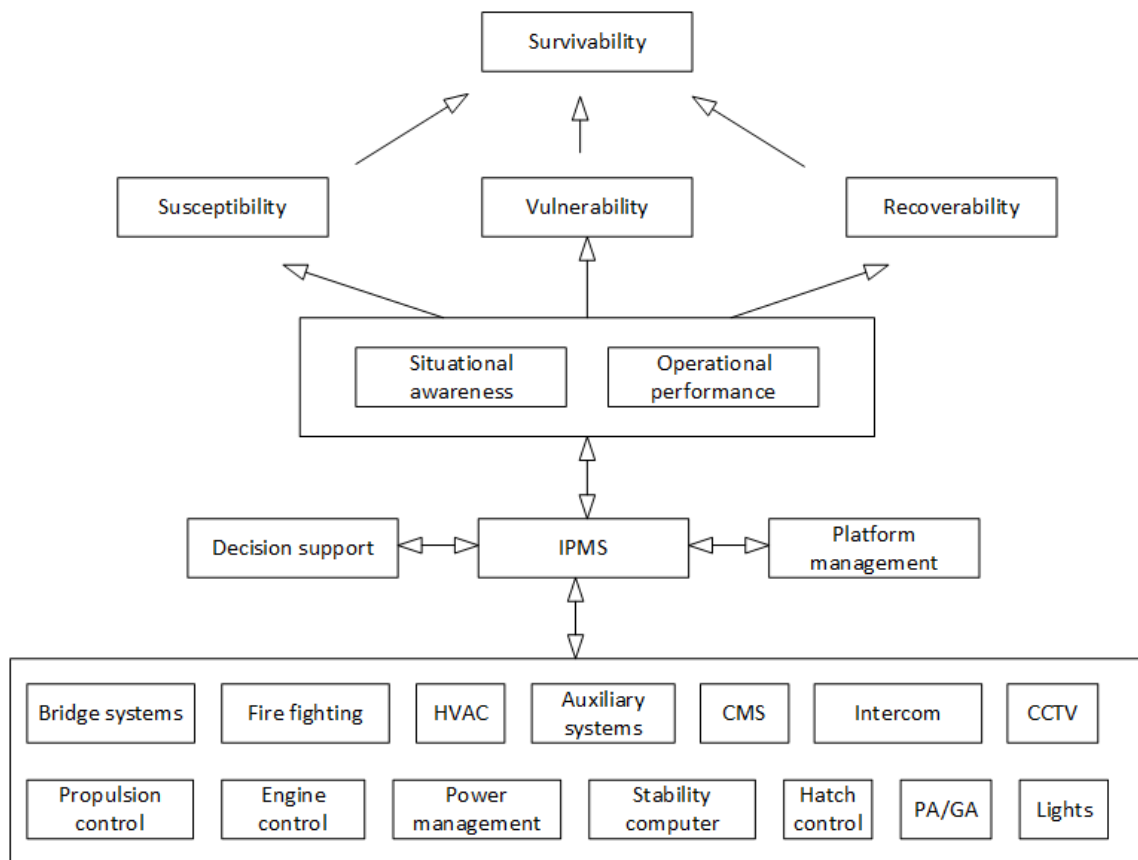


Figure 9, IPMS feature overview

6.2 Recommendations and directions for further research or development

Direct continuation for this thesis work could be a detailed design of one or all the proposed features. A model could be generated for feature evaluation. It could give information on how important each feature is or are some of the features proposed here completely useless.

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