Lecture 8:

Introduction to DP Control Systems

Course code: TMR4243

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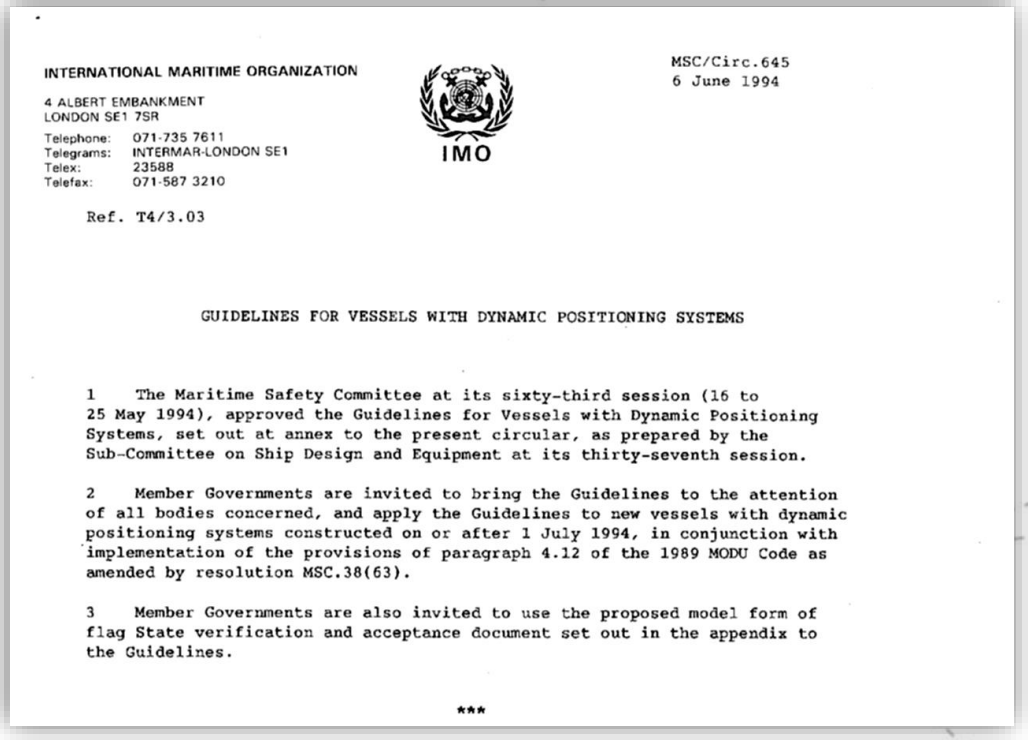
NTNU
Norwegian University of Science and Technology

IMO MSC Circ. 645



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MSC/Circ.645
6 June 1994

Ref. T4/3.03

GUIDELINES FOR VESSELS WITH DYNAMIC POSITIONING SYSTEMS

1 The Maritime Safety Committee at its sixty-third session (16 to 25 May 1994), approved the Guidelines for Vessels with Dynamic Positioning Systems, set out at annex to the present circular, as prepared by the Sub-Committee on Ship Design and Equipment at its thirty-seventh session.

2 Member Governments are invited to bring the Guidelines to the attention of all bodies concerned, and apply the Guidelines to new vessels with dynamic positioning systems constructed on or after 1 July 1994, in conjunction with implementation of the provisions of paragraph 4.12 of the 1989 MODU Code as amended by resolution MSC.38(63).

3 Member Governments are also invited to use the proposed model form of flag State verification and acceptance document set out in the appendix to the Guidelines.

***

- Definitions:
  - 1.3.1 Dynamically positioned vessel (**DP-vessel**) means a unit or a vessel which automatically maintains its position (fixed location or predetermined track) exclusively by means of thruster force.
  - 1.3.2 Dynamic positioning system (**DP-system**) means the complete installation necessary for dynamically positioning a vessel comprising the following sub-systems:
    1. power system,
    2. thruster system, and
    3. DP-control system.

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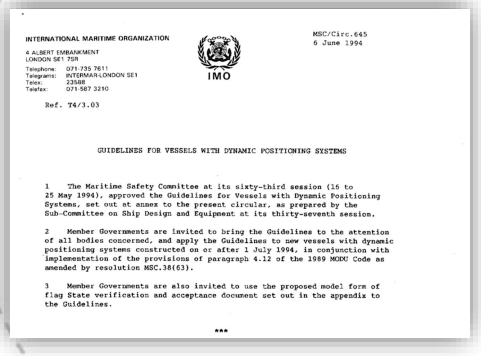

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***

- Definitions:
  - 1.3.3 Position-keeping [or **stationkeeping**] means maintaining a desired position within the normal excursions of the control system and the environmental conditions.
  - 1.3.4 **Power system** means all components and systems necessary to supply the DP-system with power. The power system includes:
    1. prime movers with necessary auxiliary systems including piping,
    2. generators,
    3. switchboards, and
    4. distributing system (cabling and cable routing).
  - 1.3.5 **Thruster system** means all components and systems necessary to supply the DP-system with thrust force and direction. The thruster system includes:
    1. thrusters with drive units and necessary auxiliary systems including piping.
    2. main propellers and rudders if these are under the control of the DP-system.
    3. thruster control electronics,
    4. manual thruster controls, and
    5. associated cabling and cable routing.

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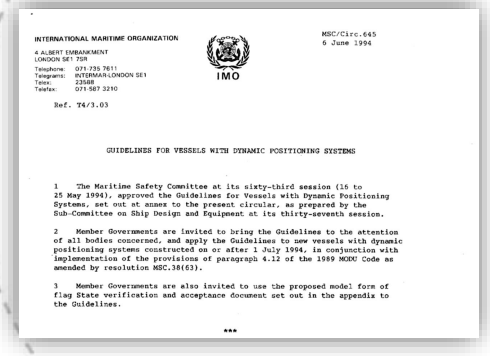

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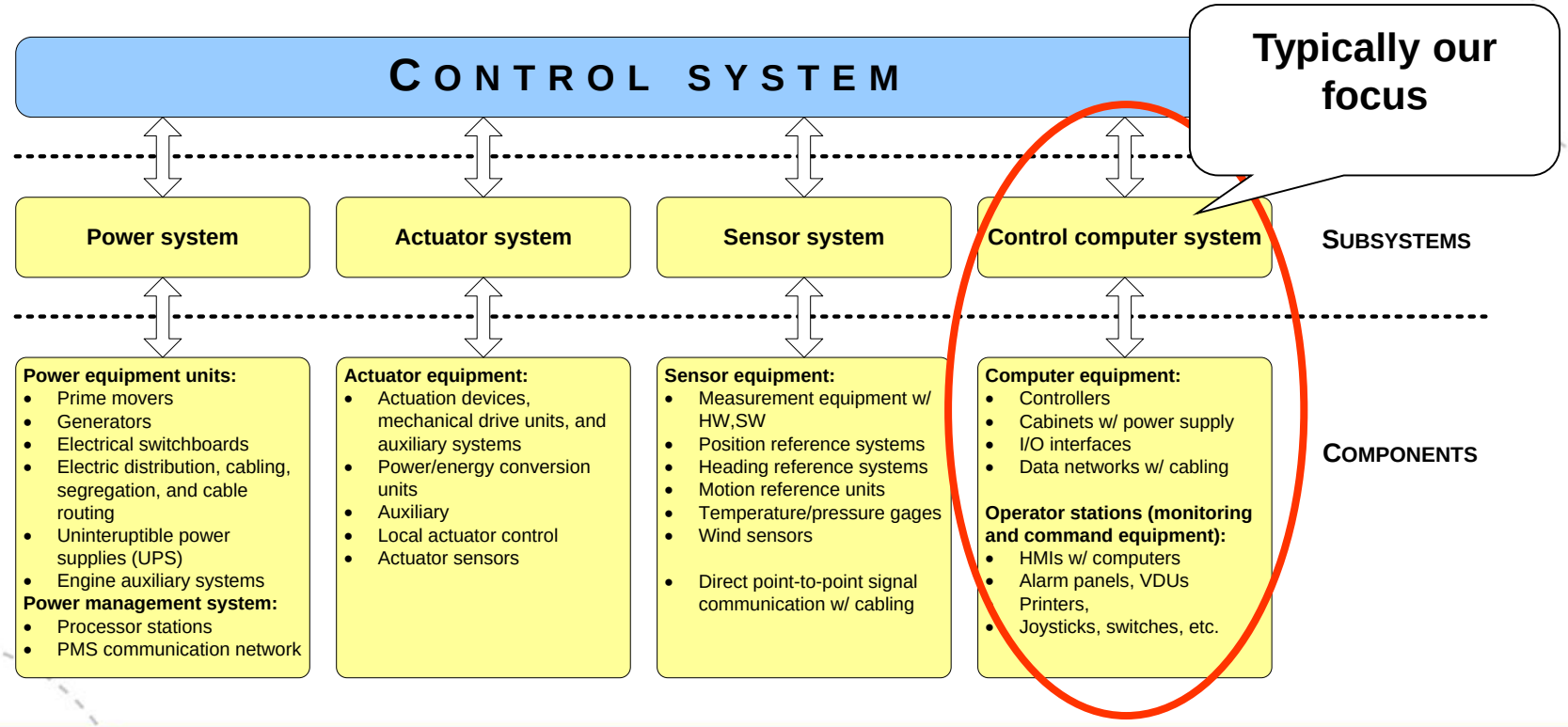
***

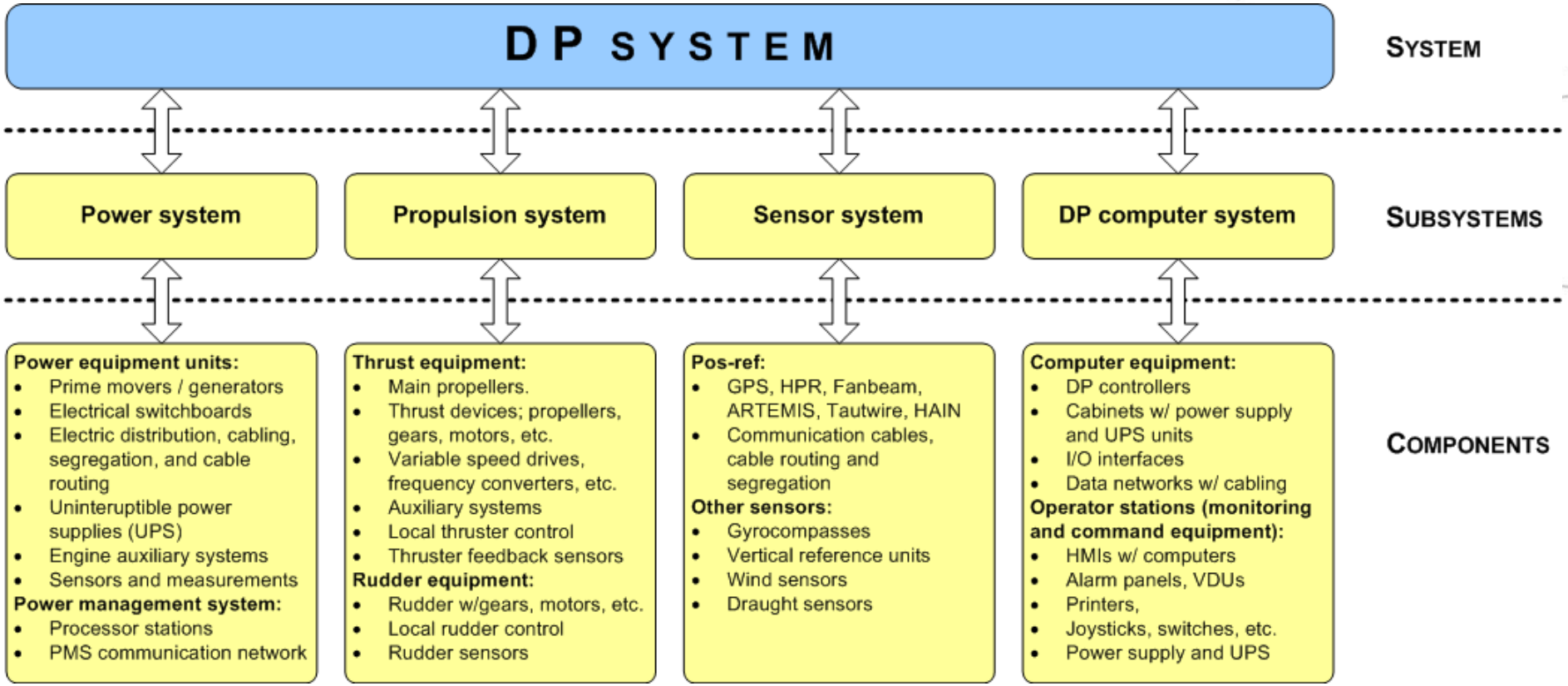
- Definitions:
  - 1.3.6 **DP-control system** means all control components and systems, hardware and software necessary to dynamically position the vessel. The DP-control system consists of the following:
    1. computer system/joystick system,
    2. sensor system,
    3. display system (operator panels),
    4. position reference system, and
    5. associated cabling and cable routing.
  - 1.3.7 **Computer system** means a system consisting of one or several computers including software and their interfaces.

Industrial control system topology

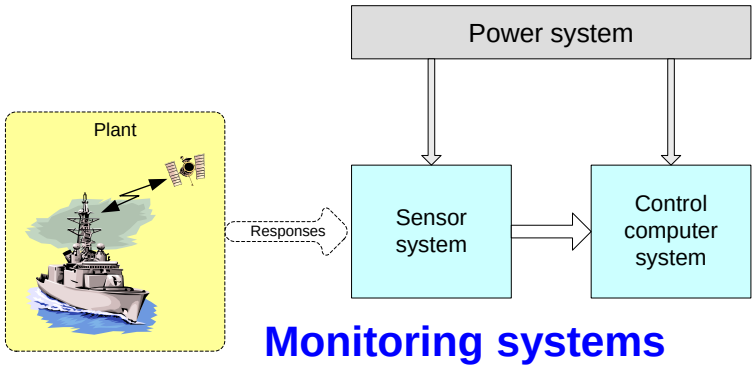
- **Control system:** All systems and components, hardware, software, and user interfaces, necessary to perform the required control function. The main subsystems are:
  - Power system.
  - Actuator system.
  - Sensor system.
  - Control computer system.



For comparison... DP system



Open-loop control systems

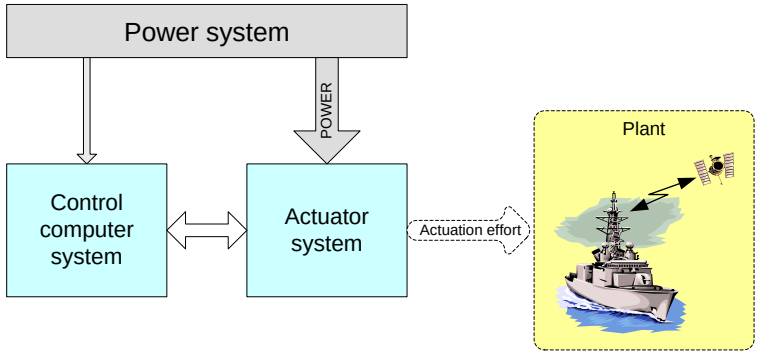


Monitoring systems

- Sensors
- Control computers
- Operator stations with monitoring and alarm panels
- Power

Command systems

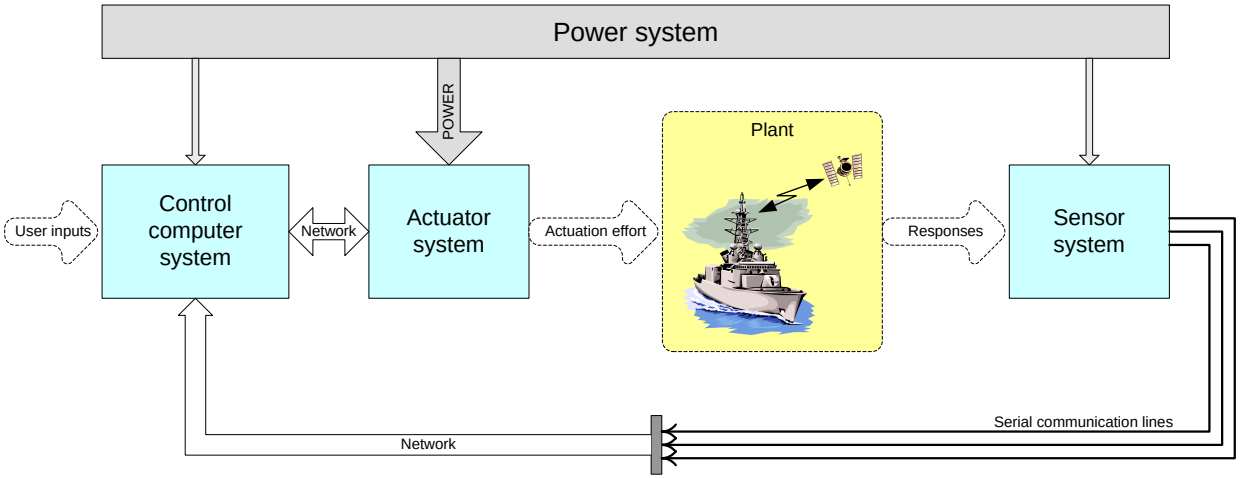
- Actuators
- Control computers
- Operator stations with joysticks, buttons, switches.
- Power



Closed-loop control system

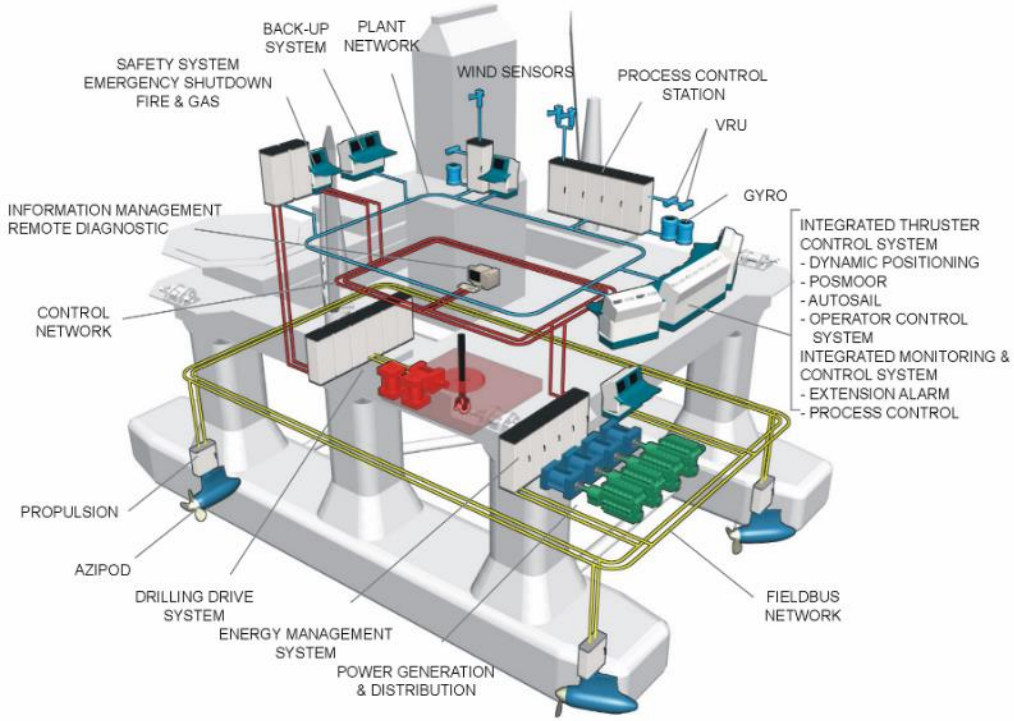
Feedback control systems

- Sensors
- Actuators
- Control computers
- Operator stations with full monitoring and command functionality
- Power



Marine Automation System

- **Automation system:** A *complex system* consisting of a stand-alone or several integrated control systems performing one or several specified autonomous control functions on one or several plant processes.



Diesel-electrical systems

- Electric power generation and distribution
- Electrical drives and rotating machinery
- Electrical propulsion

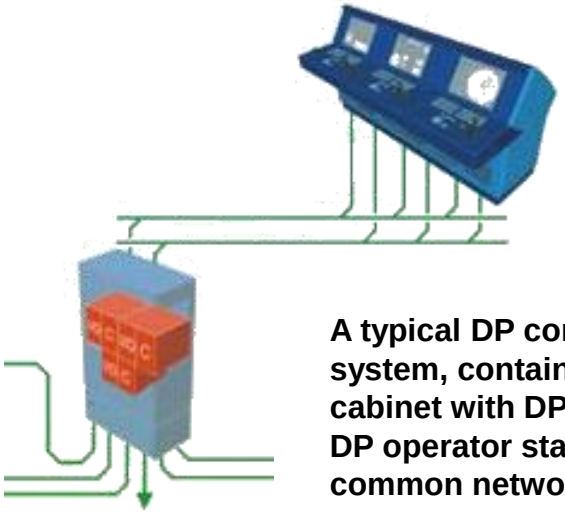
Marine Control Systems

- Machinery systems
- Ballast systems
- Loading systems
- Compressor control
- Power management
- Diagnostics and condition monitoring
- Positioning systems
- Crane control systems
- …

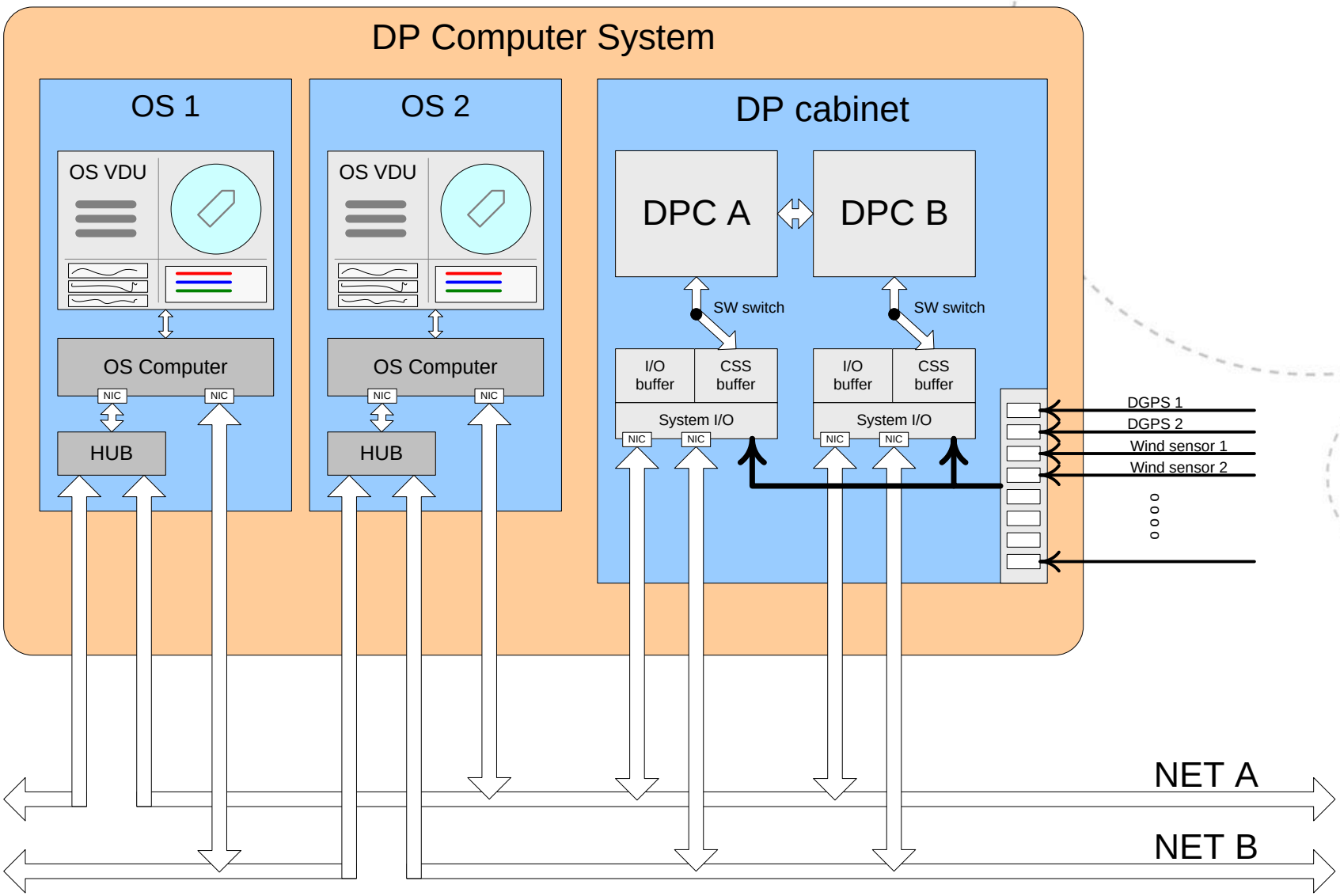
Control Computer System

- **Control computer system:** A system consisting of at least
  - one computer or processor with CPU processing and I/O capacity,
  - one or several operator stations, and
  - power supply incl. UPS units.

  The control computer system includes also
  - network, interface, and cabling for signal communication, and
  - the HW/SW platform with the controllers containing e.g. the application specific control and guidance algorithms, and the monitoring functions.

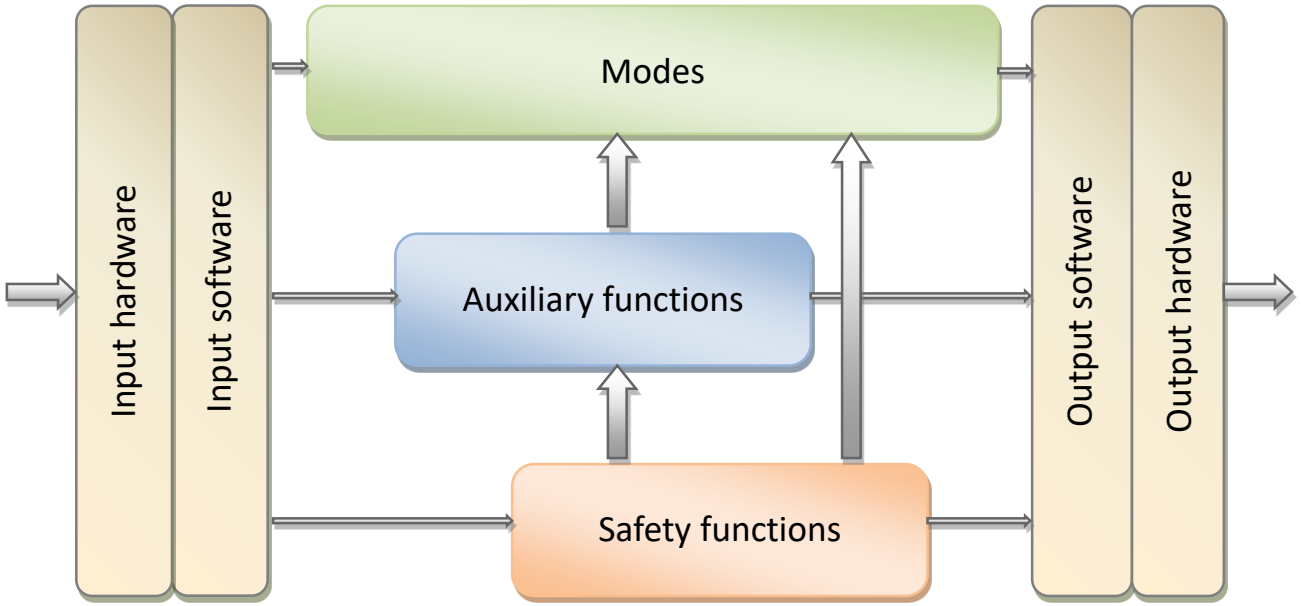


A typical DP computer system, containing a DP cabinet with DP controllers, DP operator stations, and common network.


DP Computer System
OS 1
OS VDU
OS Computer
NIC
NIC
HUB
OS 2
OS VDU
OS Computer
NIC
NIC
HUB
DP cabinet
DPC A
DPC B
SW switch
SW switch
I/O buffer
CSS buffer
I/O buffer
CSS buffer
System I/O
System I/O
NIC
NIC
NIC
NIC
DGPS 1
DGPS 2
Wind sensor 1
Wind sensor 2
NET A
NET B

System functions

- The Control Computer System is associated with a set of functions, divided among:
  - ***Modes*** *– preprogrammed configurations of functions to satisfy different intended use of the control system.*
  - ***Auxiliary functions*** *– necessary functions supporting the selected mode of operation.*
  - ***Safety functions*** *– to uphold system integrity, reduce risk of system breakdown, and facilitate safe termination of operation.*



DP functions

- Main modes:
  - Stationkeeping
  - Tracking
  - Follow target
  - Optimal heading
  - Joystick
  - Weather vaning
  - ...and several more

- Support functions:
  - Mode control and mode changes
  - Kalman filtering/Dynamic vessel model
  - Wind force feedforward
  - Error force estimate/DP Current
  - External force compensation
  - IO signal filtering and integrity control
  - Sensor signal fusion (selection, voting, weighting, etc.)
  - Thruster allocation/reallocation
  - Blackout prevention (thruster load limitation)
  - Online capability analysis
  - Online motion prediction
  - HMI – buttons and change-over switches
  - Alarm and messaging system

- Safety functions:
  - Online/Hot DP controller automatic change-over.
  - Dead reckoning.
  - Online Consequence analysis.
  - DP class monitoring.
  - Backup monitoring

DP as a package of technological products

DP layout

Control law:

$$\sigma = \eta - \eta_d$$

$$\tau = -K_i R(\psi)^\top \sigma - K_p R(\psi)^\top (\eta - \eta_d) - K_d \nu - f_{wnd}$$

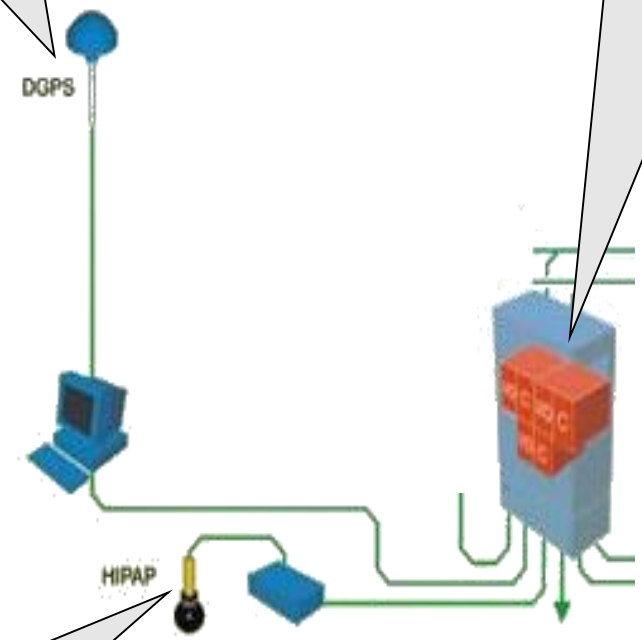
Courtesy: Kongsberg Maritime

DP layout

Control law:

$$\sigma = \eta - \eta_d$$
$$\tau = -K_i R(\psi)^\top \sigma - K_p R(\psi)^\top (\eta - \eta_d) - K_d \nu - f_{wnd}$$

Position Reference System: DGPS



Position Reference System: HPR

Courtesy: Kongsberg Maritime

DP layout

Control law:

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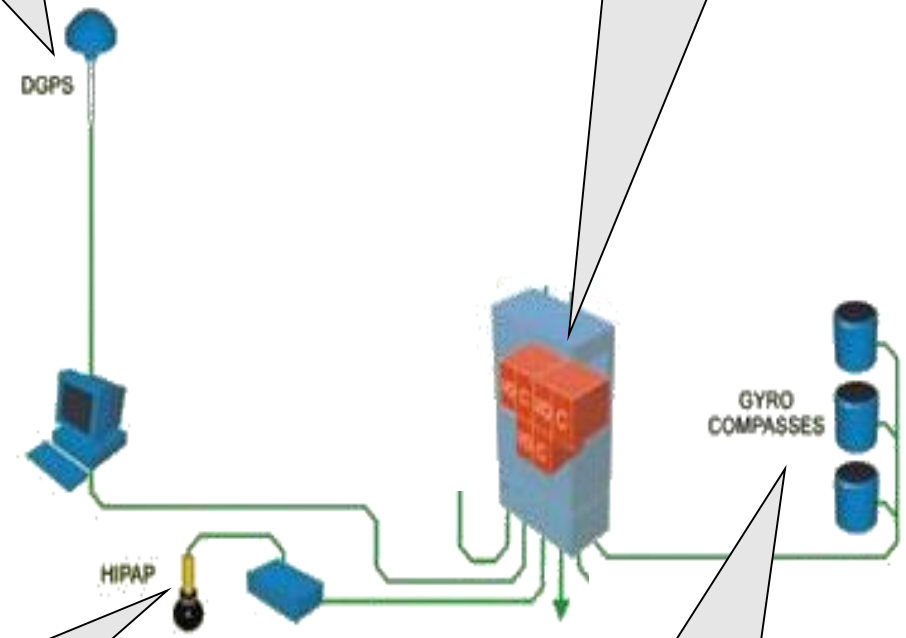

Courtesy: Kongsberg Maritime

Position Reference System: HPR

Heading Reference System: Gyrocompass

DP layout

Control law:

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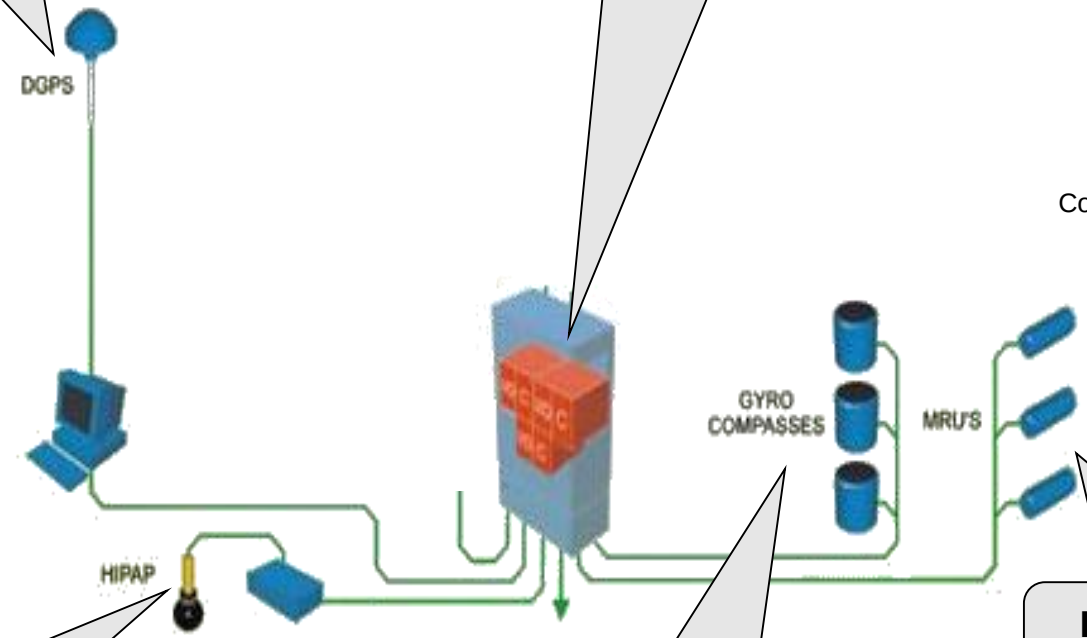


Courtesy: Kongsberg Maritime

Position Reference System: HPR

Heading Reference System: Gyrocompass

Lever arm correction: Motion Reference Units

DP layout

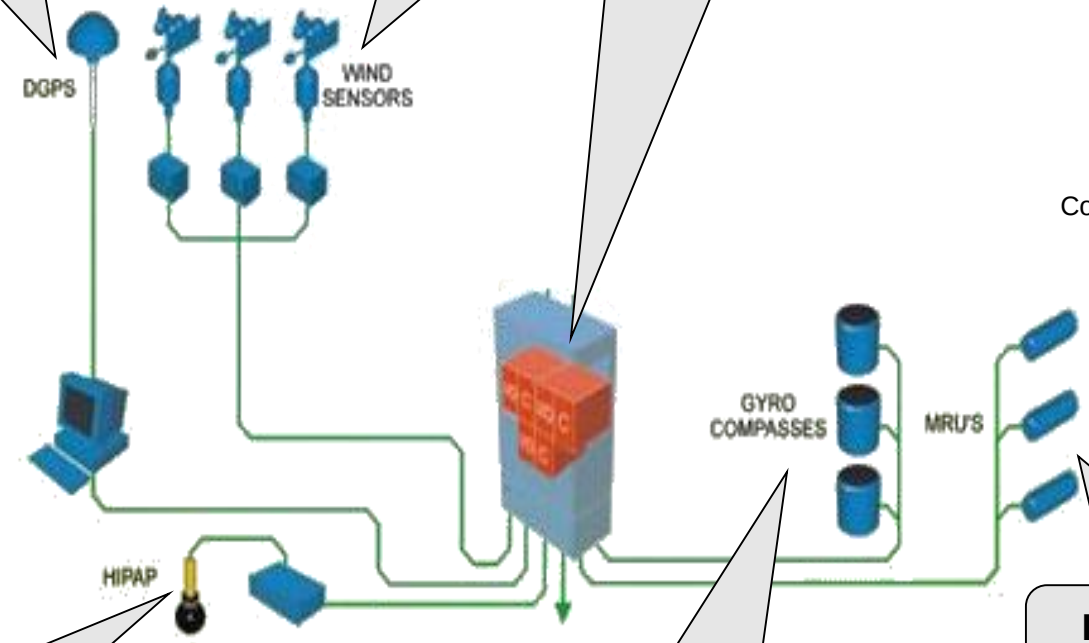
Control law:

$$\sigma = \eta - \eta_d$$
$$\tau = -K_i R(\psi)^\top \sigma - K_p R(\psi)^\top (\eta - \eta_d) - K_d \nu - f_{wnd}$$

Position Reference System: DGPS

Wind sensors:

$$f_{wnd} = g(u_{wnd}, \alpha_{wnd})$$



Courtesy: Kongsberg Maritime

Position Reference System: HPR

Heading Reference System: Gyrocompass

Lever arm correction: Motion Reference Units

DP layout

Control law:

$$\sigma = \eta - \eta_d$$
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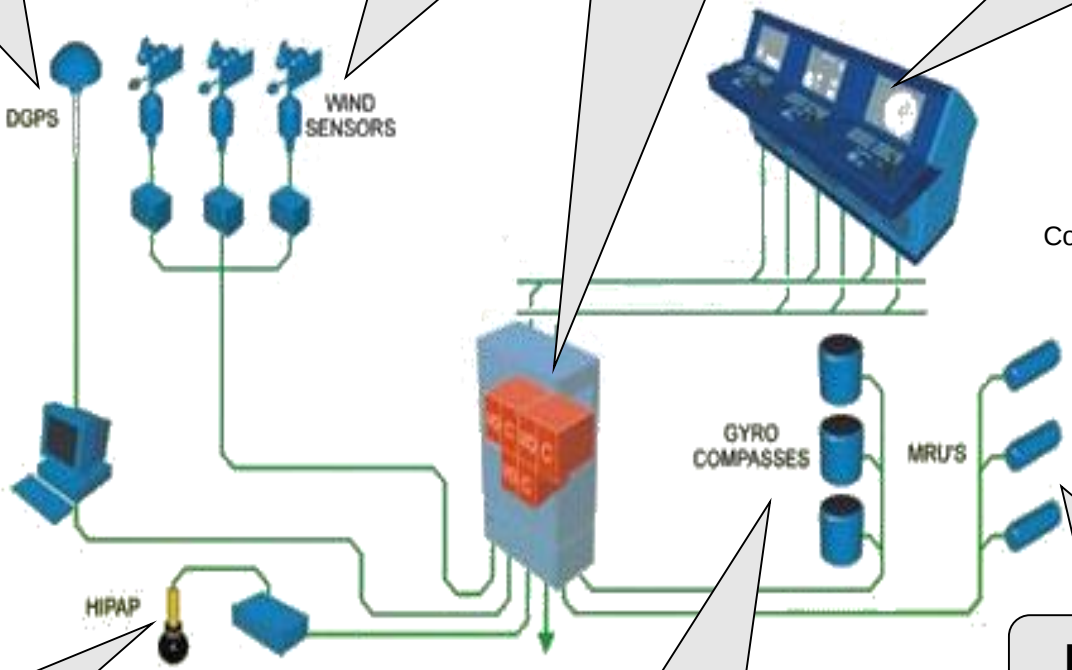
Position Reference System: DGPS

Wind sensors:

$$f_{wnd} = g(u_{wnd}, \alpha_{wnd})$$

Human Machine Interfaces: Operator Stations



Courtesy: Kongsberg Maritime

Position Reference System: HPR

Heading Reference System: Gyrocompass

Lever arm correction: Motion Reference Units

DP layout

Control law:

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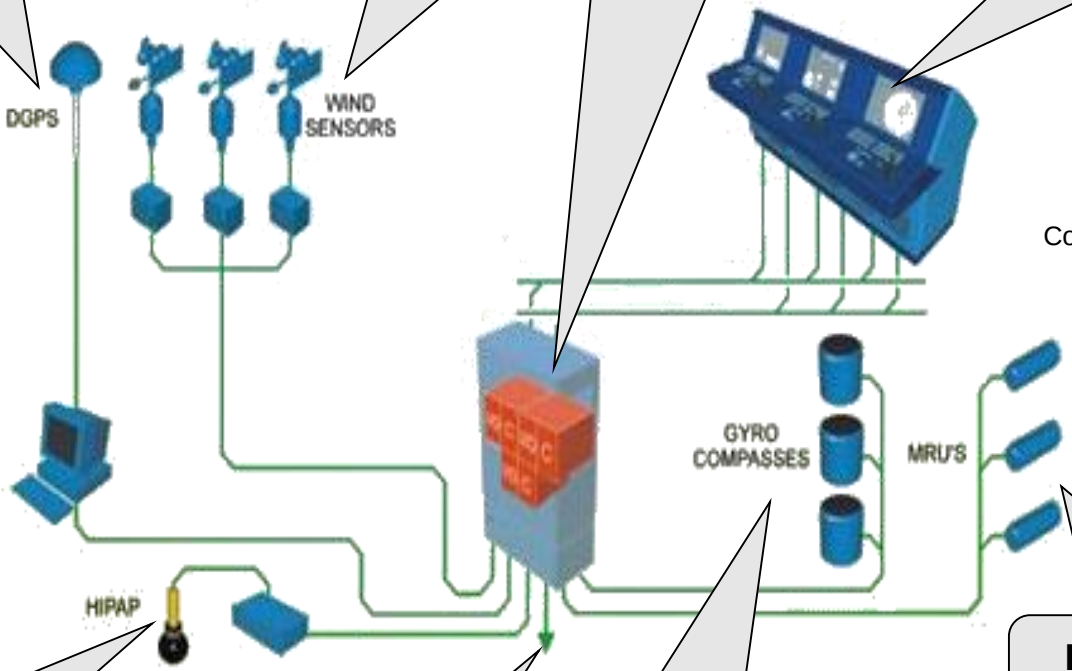
Position Reference System: DGPS

Wind sensors:

$$f_{wnd} = g(u_{wnd}, \alpha_{wnd})$$

Human Machine Interfaces: Operator Stations



Courtesy: Kongsberg Maritime

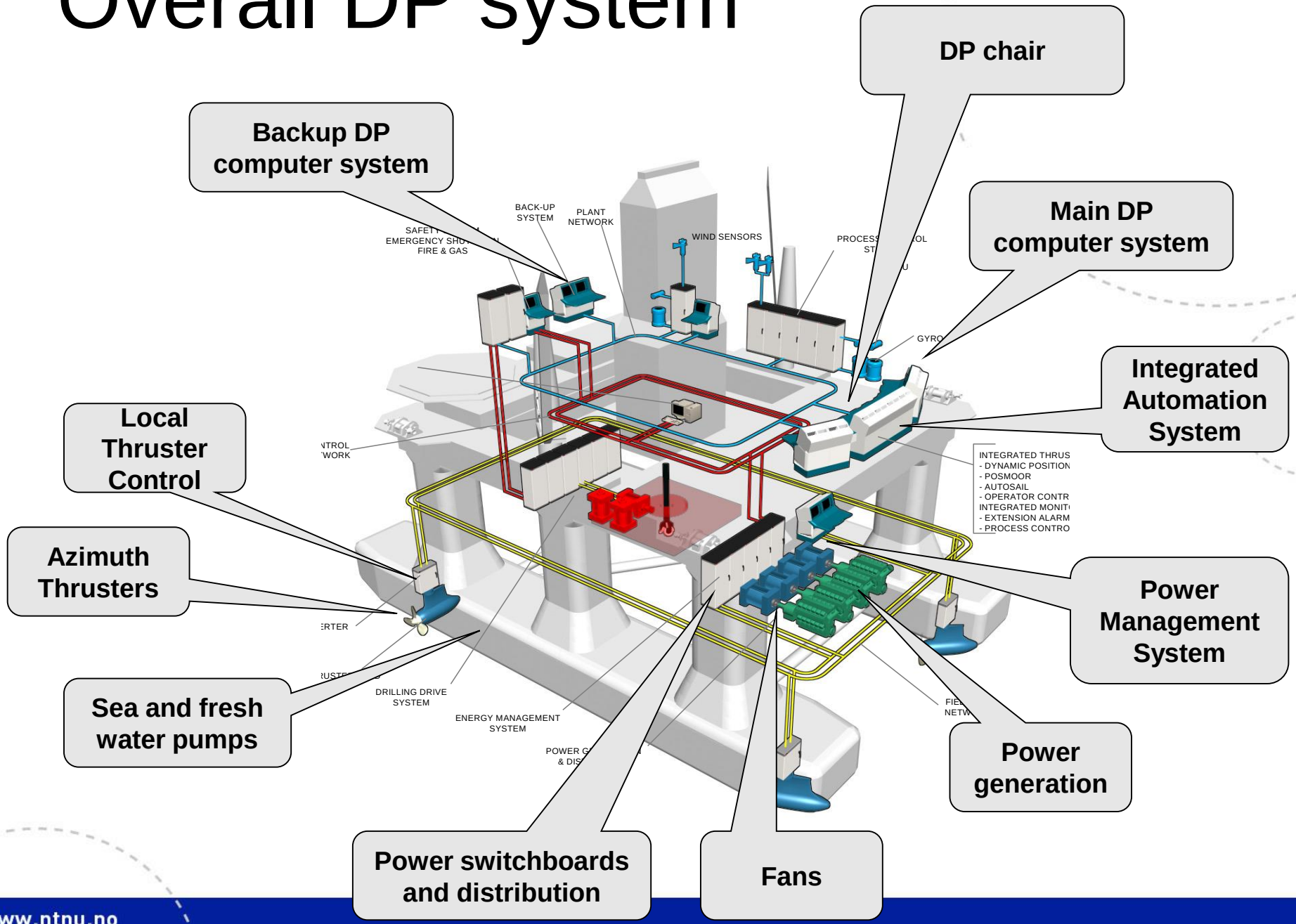
Position Reference System: HPR

Thruster commands (setpoints)

Heading Reference System: Gyrocompass

Lever arm correction: Motion Reference Units

Overall DP system



Operational aspects

DPO and training

Courtesy: SMS

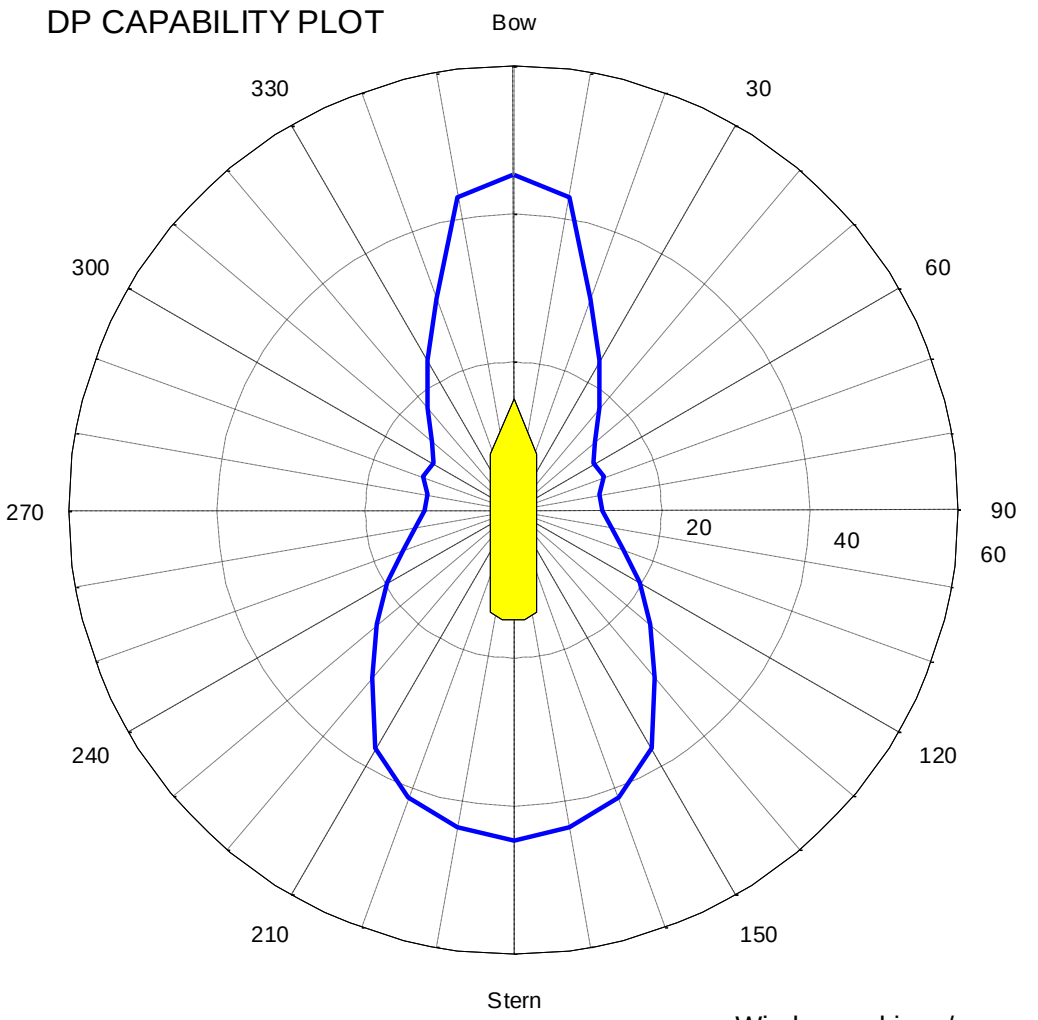
DP chair

- Complete access to monitoring of DP processes, alarm centre, and control of thrusters and power system.
- Ergonomic considerations
- Cognitive considerations: What information should be given to DPO?
  - All that is necessary, but...
  - not too much.
- Integration with other systems?
  - Different vendors is a problem.
  - There are today several “total ship system suppliers”

Courtesy: Kongsberg Maritime

Vessel capability

- Capability is the amount of thrust that can be produced in all directions to oppose environmental forces on the ship structure.
- Given a thruster configuration, the DP Capability plot shows directly the limits w.r.t. wind, waves, and current the vessel can counteract.
- Hence, an iterative approach calculating the capability plots for your proposed thruster configurations can be utilized.



Rules and Regulations

- IMO: International Maritime Organization
  - SOLAS – Safety Of Life At Sea.
  - MODU – Mobile Offshore Drilling Units.
  - MSC/Circ. 645 – Guidelines for Vessels with DP systems.
- Flag state legislation
  - The Norwegian Maritime Directorate (NMD)
  - US coast guard
  - EU directives
- Coastal requirements
  - Petroleum Safety Authority Norway (PSA)
- Classification societies
  - DNV, LRS, ABS, BV, etc.
- Industrial requirements
  - IMCA – International Marine Contractors Association
  - StatoilHydro, Shell, etc.
- International Standards:
  - ISO, IEC, IEEE, etc.

Risk reduction philosophy: Redundancy and segregation

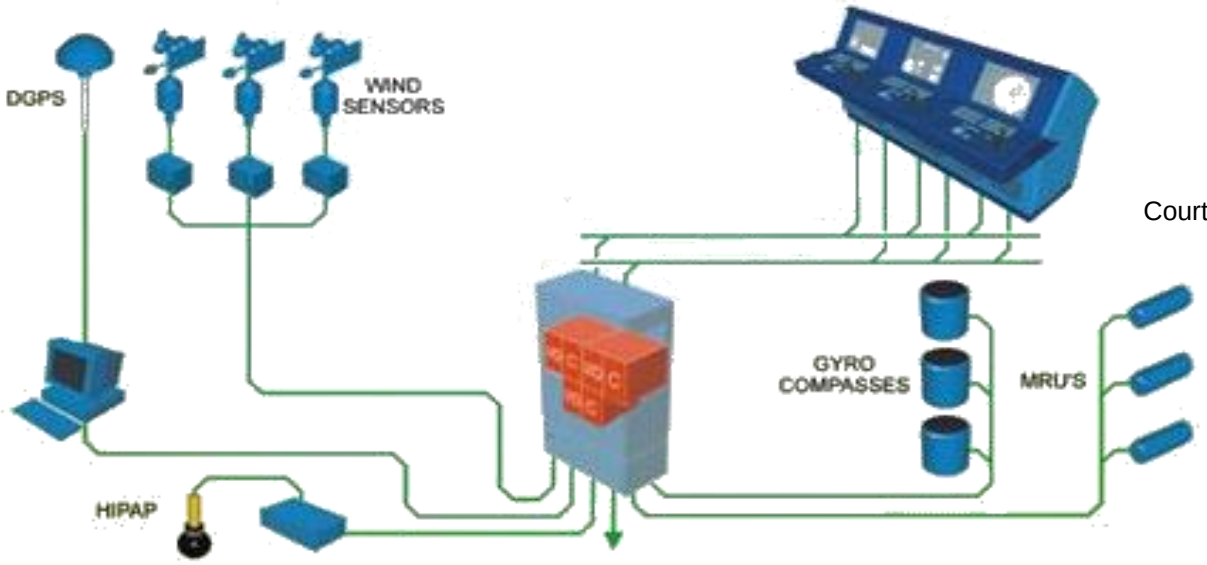
Main risk:

LOSS OF POSITION

Redundancy

- **Redundancy:** [IEEE 610.12-1990] The presence of auxiliary components in a system to perform the same or similar functions as other elements for the purpose of preventing or recovering from failures.
  - *Active redundancy* is the use of redundant elements operating simultaneously to prevent, or permit recovery from, failures.
  - *Standby redundancy* is the use of redundant elements that are left inoperative until a failure occurs in a primary element.

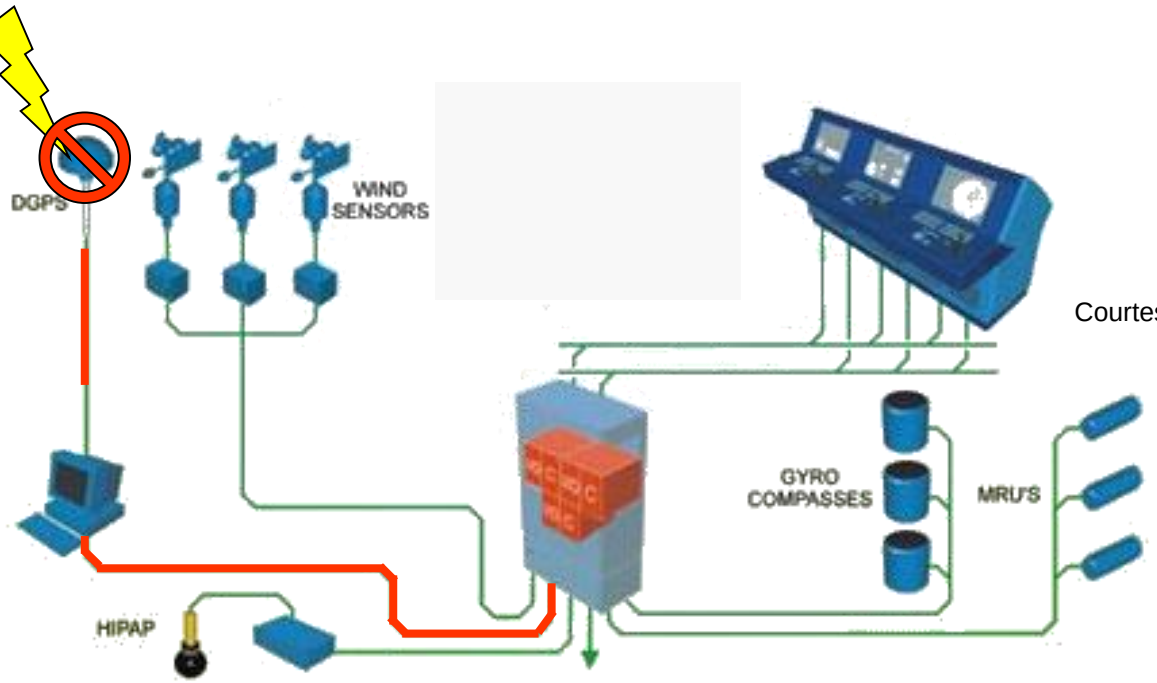
- Hardware redundancy – duplicating components.
- Software redundancy functions
  - Signal voting, weighting, selection, etc.



Courtesy: Kongsberg Maritime

Faults, failures, and failure modes

- **FAULT:** A defect in a component, e.g. short circuit, SW bug, etc.
- **FAILURE:** The inability of the component to perform its function.
- **FAILURE MODE:** The functional manifestation of the failure, observed at the boundary of the component, e.g. on output signals.



Courtesy: Kongsberg Maritime

Faults, failures, and failure modes

- **So,… many FAULTS result in the same**

  FAILURE,

- **and… many FAILURES are manifested by the same**

  FAILURE MODES

- **Hence,… in fault analysis one should consider the system with respect to a perhaps manageable set of FAILURE MODES.**

Signal failures modes

- **Signal failure mode:** The physical effect of a signal failure, typically categorized among:
  - *Scaling error* – the true signal is scaled erroneously.
  - *Wild point error* – wild-points are corrupting the true signal due to e.g. bad software, hardware, or interference.
  - *Bias error* – the signal has a bias relative to the true signal.
  - *Drift error* – the signal drifts off relative to the true signal, either by a stochastic process (Wiener process) or deterministically (ramp).
  - *Noise error* – the true signal is corrupted by a large noise, e.g. Gaussian white noise or a 1st order Markov process.
  - *Signal freeze* – the signal freezes at some value.
  - *Signal@boundary* – the signal is fixed at a boundary of its valid range, e.g. at +10V for an analog signal due to a broken signal wire.
  - *Signal out-of-range* – the signal enters an invalid value range.
  - *Loss of signal* – the signal stops being communicated.
  - *Network message failures* – deteriorated transmission of signal messages, e.g. erroneous status bits, slow transmission rate, empty messages, network storm, etc.
  - *Telegram format failures* – errors in digital format representing signal.
  - *Flags*: Signal integrity flags, status bits, quality indicators, etc., are set erroneously. Also message checksum errors.

Why?

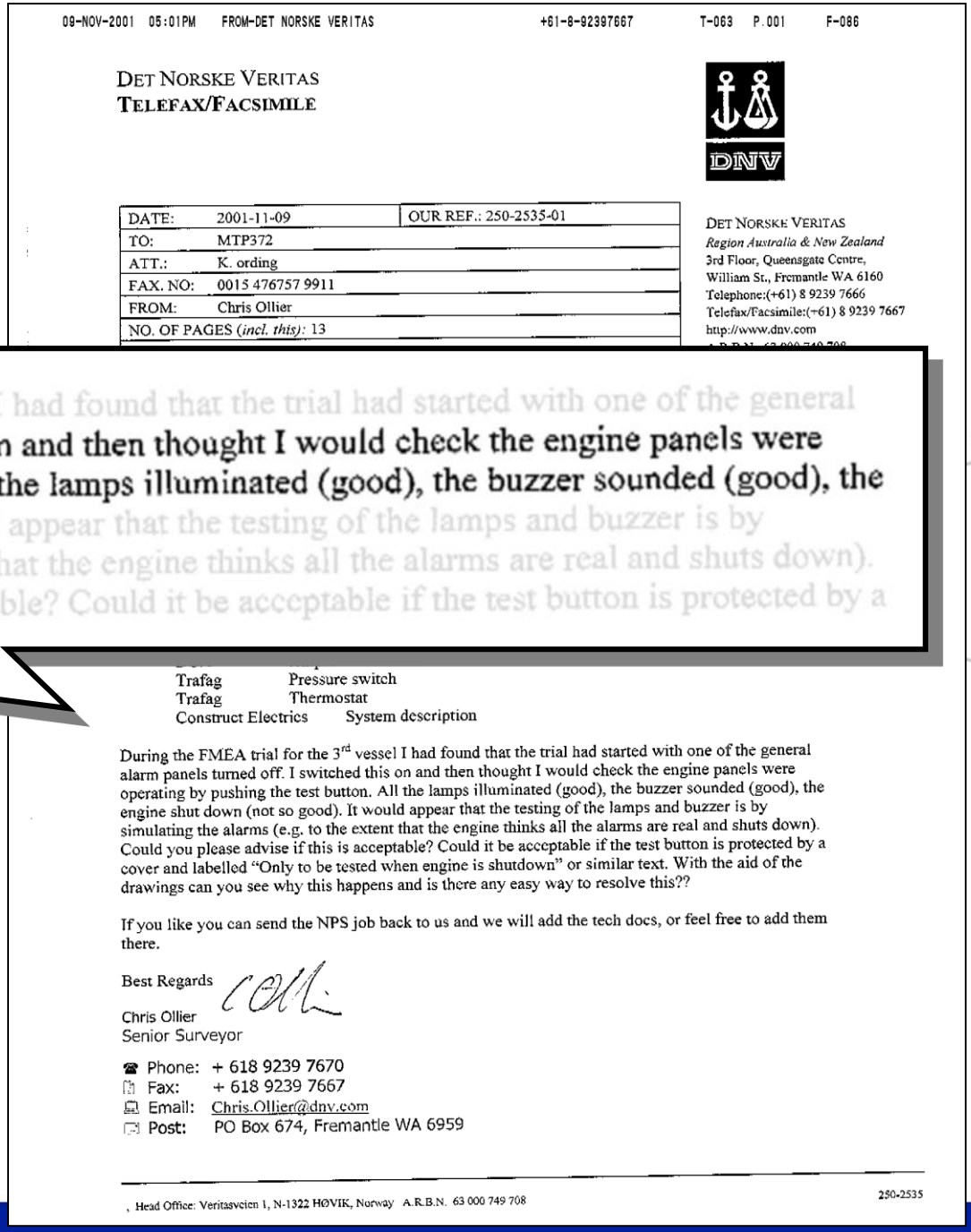
Why barriers and safety functions?

Why redundancy?

Why fault-tolerant control?

Why so much testing and verification?

Example



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During the FMEA trial for the 3rd vessel I had found that the trial had started with one of the general alarm panels turned off. I switched this on and then thought I would check the engine panels were operating by pushing the test button. All the lamps illuminated (good), the buzzer sounded (good), the engine shut down (not so good). It would appear that the testing of the lamps and buzzer is by simulating the alarms (e.g. to the extent that the engine thinks all the alarms are real and shuts down). Could you please advise if this is acceptable? Could it be acceptable if the test button is protected by a

Trafag Pressure switch
Trafag Thermostat
Construct Electrics System description

During the FMEA trial for the 3rd vessel I had found that the trial had started with one of the general alarm panels turned off. I switched this on and then thought I would check the engine panels were operating by pushing the test button. All the lamps illuminated (good), the buzzer sounded (good), the engine shut down (not so good). It would appear that the testing of the lamps and buzzer is by simulating the alarms (e.g. to the extent that the engine thinks all the alarms are real and shuts down). Could you please advise if this is acceptable? Could it be acceptable if the test button is protected by a cover and labelled "Only to be tested when engine is shutdown" or similar text. With the aid of the drawings can you see why this happens and is there any easy way to resolve this??

If you like you can send the NPS job back to us and we will add the tech docs, or feel free to add them there.

Best Regards

Chris Ollier
Senior Surveyor

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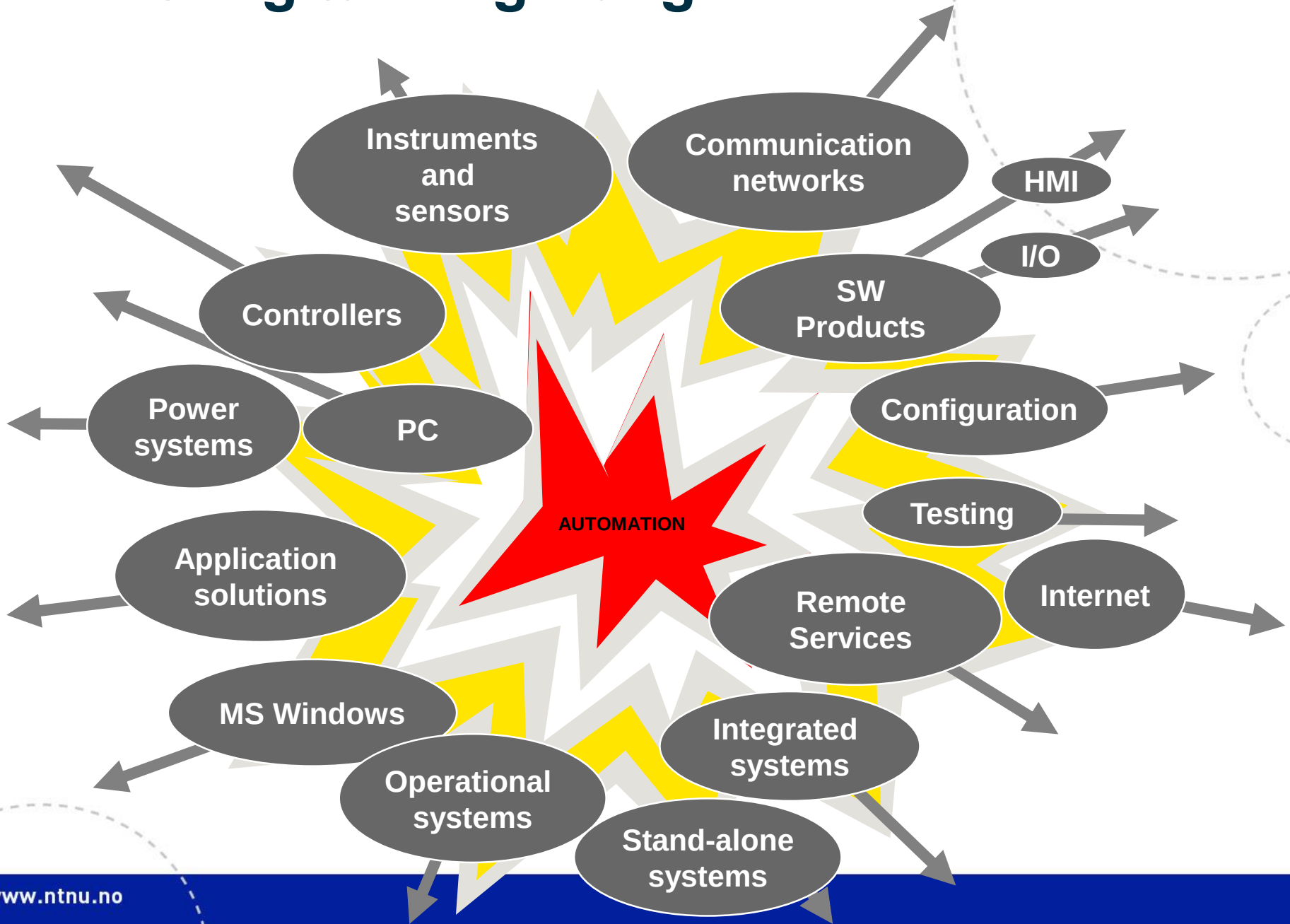
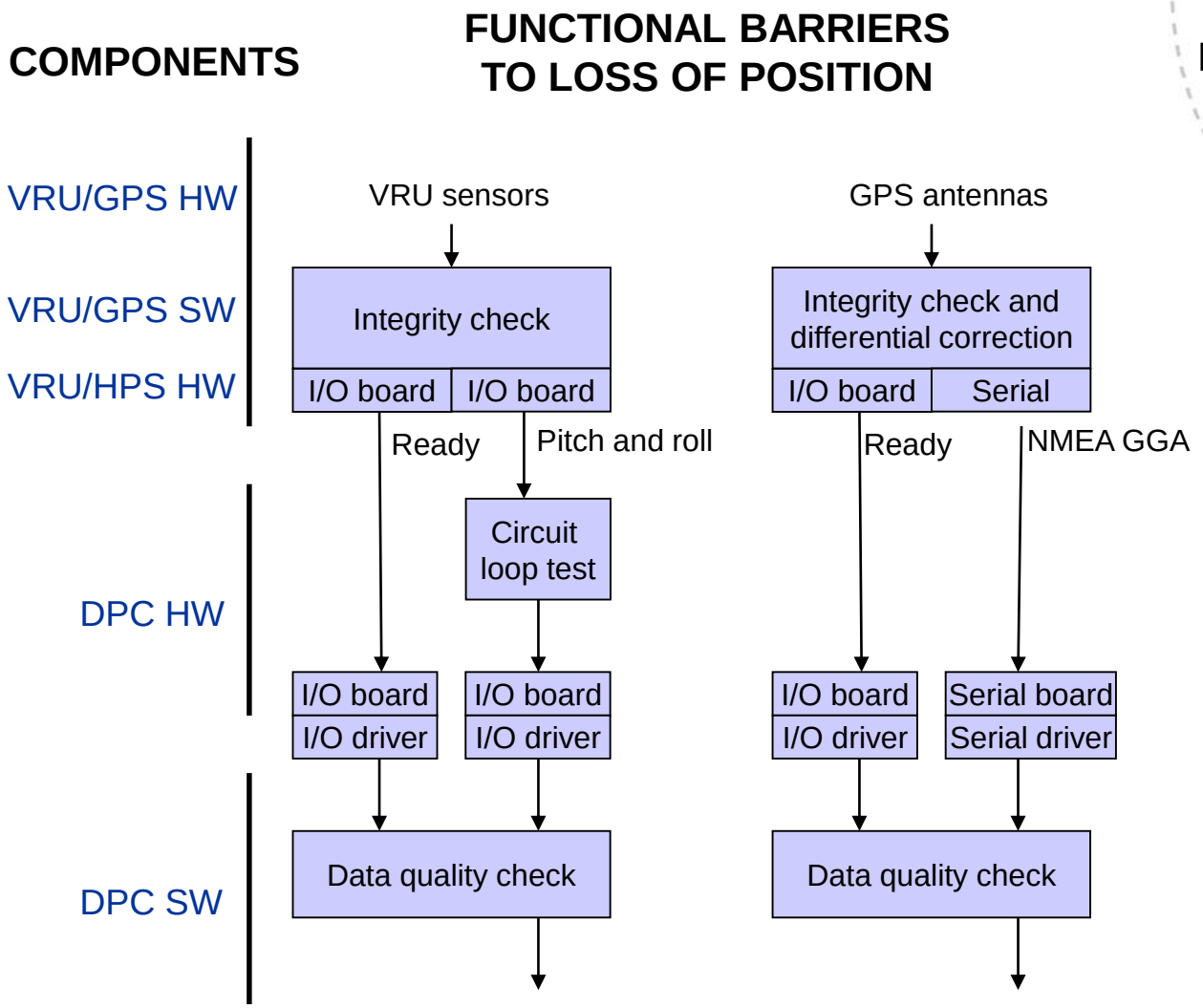
The Digital “Big Bang”



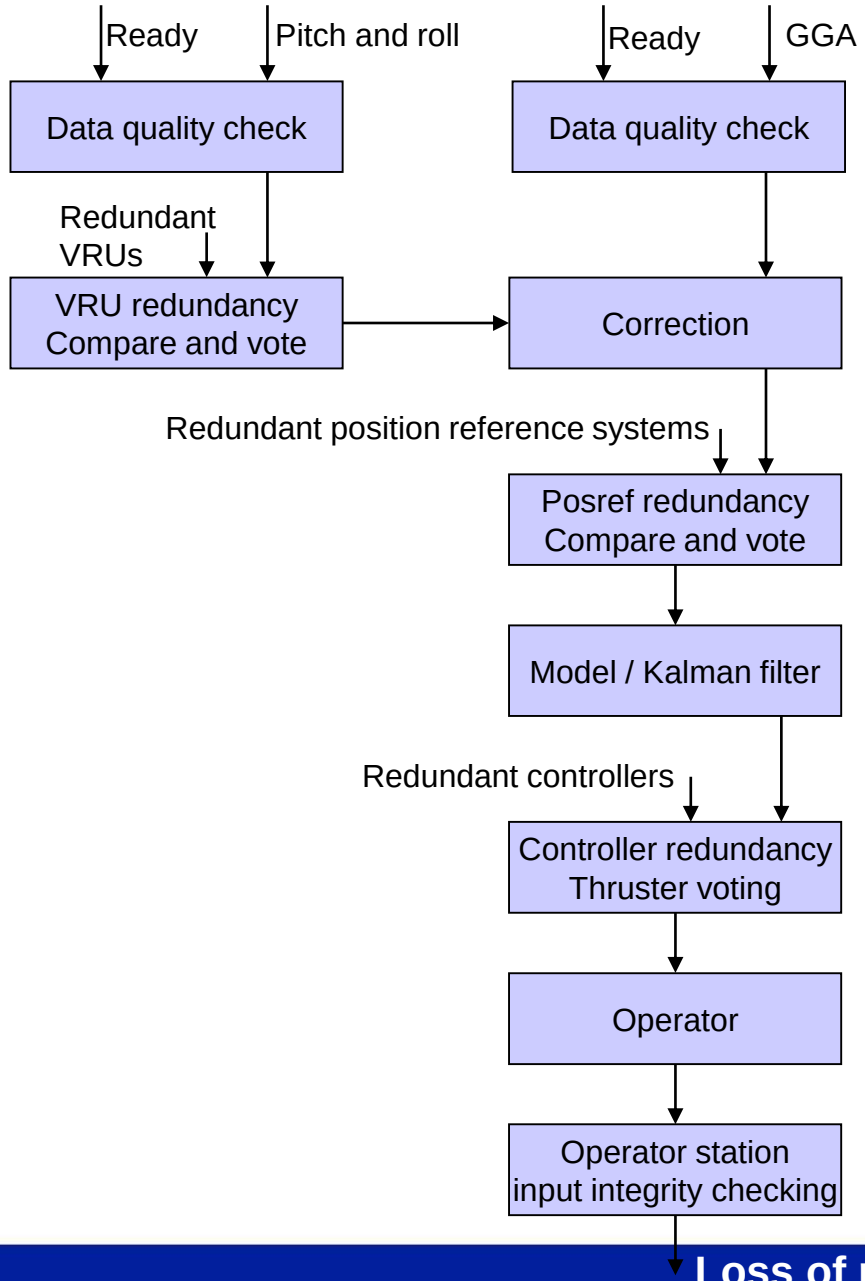
Example: Barriers to loss of position due to VRU and DGPS failure modes



COMPONENTS

FUNCTIONAL BARRIERS TO LOSS OF POSITION

FAILURE MODES



DPC SW

PSU HW

Operator

Operator station

Noise
Wild points
Format error
Integrity errors
Freeze

Bias (difference or median reject)
Drift (difference or median reject)

Noise
Bias (prediction error)
Drift (prediction error)

Controller HW failure
Controller SW errors
Loss of power / UPS
Transmission errors
Network errors

Everything else

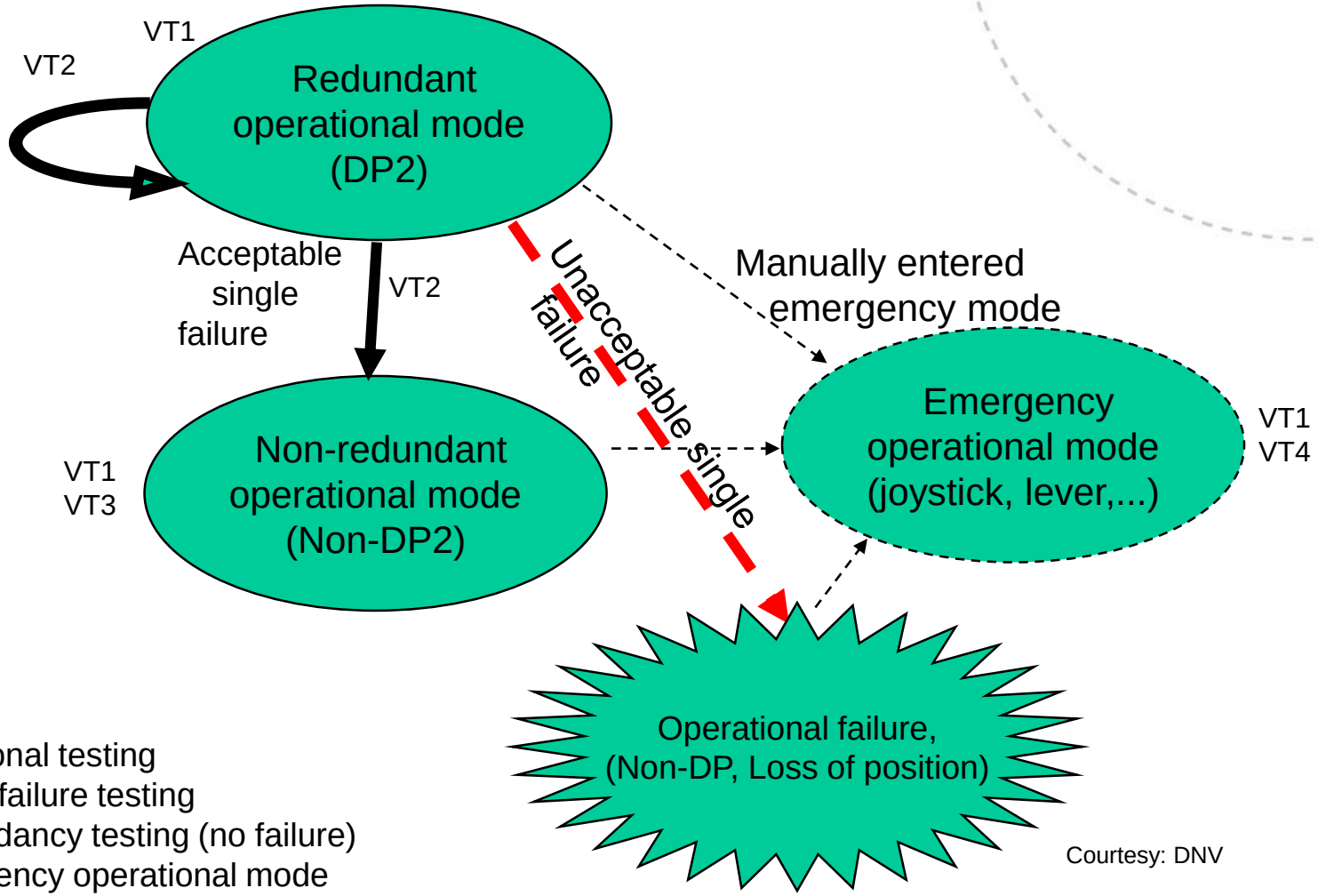
Operator errors

Main objective of testing and verification

Safety philosophy:

- **FAILURES DO/WILL HAPPEN**
- **But, WORST-CASE FAILURE shall not result in LOSS-of-POSITION**

Objective of testing: Example of a DP system



VT1: Functional testing
VT2: Single failure testing
VT3: Redundancy testing (no failure)
VT4: Emergency operational mode

Courtesy: DNV

IMO MSC/Circ.645 – Guidelines for Vessels with Dynamic Positioning Systems

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MSC/Circ.645
6 June 1994

Ref. T4/3.03

GUIDELINES FOR VESSELS WITH DYNAMIC POSITIONING SYSTEMS

1 The Maritime Safety Committee at its sixty-third session (16 to 25 May 1994), approved the Guidelines for Vessels with Dynamic Positioning Systems, set out at annex to the present circular, as prepared by the Sub-Committee on Ship Design and Equipment at its thirty-seventh session.

2 Member Governments are invited to bring the Guidelines to the attention of all bodies concerned, and apply the Guidelines to new vessels with dynamic positioning systems constructed on or after 1 July 1994, in conjunction with implementation of the provisions of paragraph 4.12 of the 1989 MODU Code as amended by resolution MSC.38(63).

3 Member Governments are also invited to use the proposed model form of flag State verification and acceptance document set out in the appendix to the Guidelines.

***

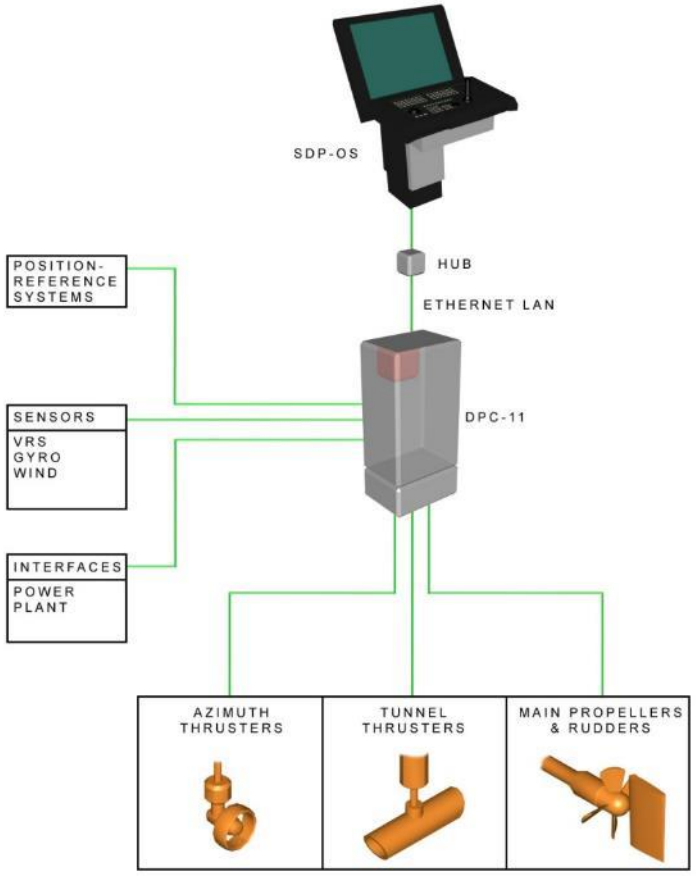
IMO MSC/Circ.645 – Guidelines for Vessels with Dynamic Positioning Systems

- Equipment classes:
  - The equipment classes are defined by their worst case failure modes as follows:
    1. **(DP1) For equipment class 1, loss of position may occur in the event of a single fault.**
    2. **(DP2) For equipment class 2, a loss of position is not to occur in the event of s single fault in any active component or system. Formally static components will not be considered to fail where adequate, protection from damage is demonstrated, and reliability is to the satisfaction of the Administration. Single failure criteria include:**
       - Any active component or system (generators, thrusters, switchboards, remote controlled valves, etc.)
       - Any normally static component (cables, pipes, manual valves, etc.) which is not properly documented with respect to protection and reliability.
    3. **(DP3) For equipment class 3, a single failure includes:**
       - Items listed above for class 2 and any normally static component is assumed to fail.
       - All components in any one watertight compartment, from fire or flooding.
       - All components in any one fire sub-division, from fire or flooding (for cables, see also 3.5.1)

IMO Class 1

- DP Control System 1
- Independent Joystick System1
- Position Reference Systems 1
- Sensors
  - Gyro 1
  - VRU 1
  - Wind 1
- UPS 1

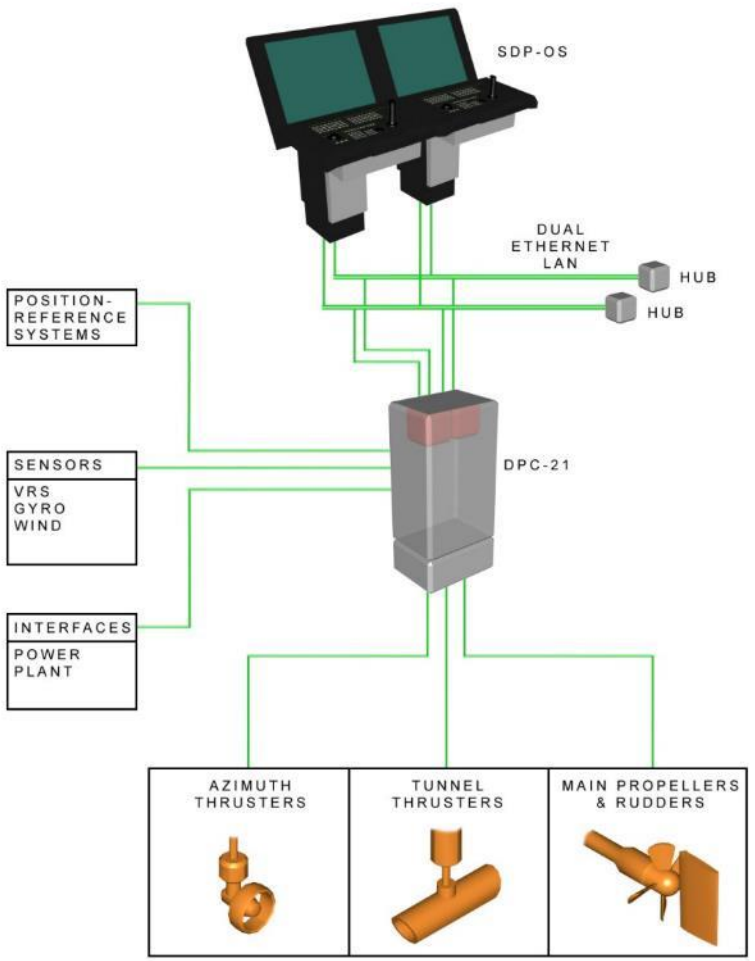
Courtesy: Kongsberg Maritime



IMO Class 2

- DP Control System 2
  - Computer Redundancy
  - Failure Detection
  - Fault Isolation
  - Dual Network
- Independent Joystick System 1
- Position Reference Systems 3
- Sensors
  - Gyro 3
  - VRU 2 / 3
  - Wind 2
- UPS 2

Courtesy: Kongsberg Maritime

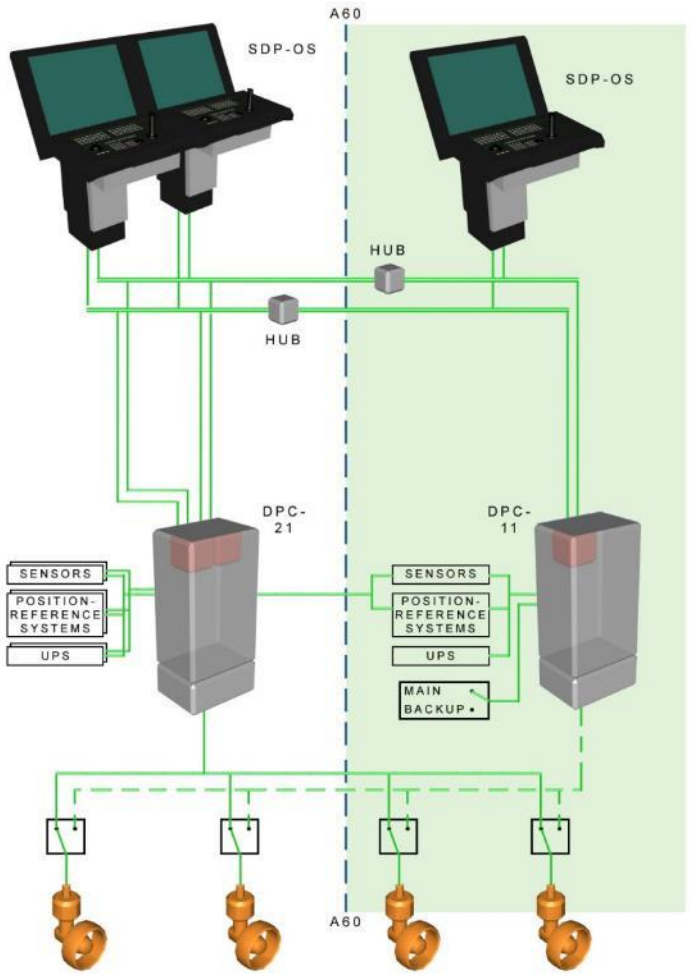


Consequence Analysis

IMO Class 3

- Main DP control system 2
- Backup DP control system 1
- Independent Joystick System 1
- Position Reference Systems 3 / 1
- Sensors
  - Gyro 2 + 1
  - VRU 2 + 1
  - Wind 2 + 1
- UPS 2 + 1

Courtesy: Kongsberg Maritime



Consequence Analysis

I hope you don’t think DP systems are simple? ...

I hope you don’t think industrial safety-critical systems are easy? ...

Fault-tolerant control is likely a main topic of your work in your future job.