TÉCNICO LISBOA

FES

Equipment and Systems Reliability

Qualitative and quantitative reliability analysis of a system

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INTRODUCTION

The aim of our work is to carry out a preliminary qualitative and quantitative reliability analysis of a ship's steering system. More specifically, the system represented illustrates a latest-generation system on board a commercial ship, which is assisted in its navigation by an automatic pilot system integrated into the steering system.

We will see subsequently in the specific the components that represent this system and their analysis in the contexts of use, through representations of developments relative to the Failure Mode and Effect Analysis (FMEA) that identifies the main failure modes and effects of failure of the system main components and subsequently the development of a simple reliability model of the system (FTA/RBD) for qualitative and quantitative analysis of the system.

The general definition with which to introduce this work relates to what a ship's steering system is, more specifically is a mechanism used to maneuver the ship. When the ship is at sea, it is constantly in operation, and any failure or malfunction might lead to tragedy. A steering system typically consists of the following components: a steering gear, control equipment, a rudder carrier, a rudder, and a rudder horn. In response to a signal from the bridge, the steering gear moves the rudder. The control equipment receives a signal from the bridge indicating the specified rudder angle and operates the steering gear to move the rudder to the appropriate angle.

DESCRIPTION OF THE SYSTEM

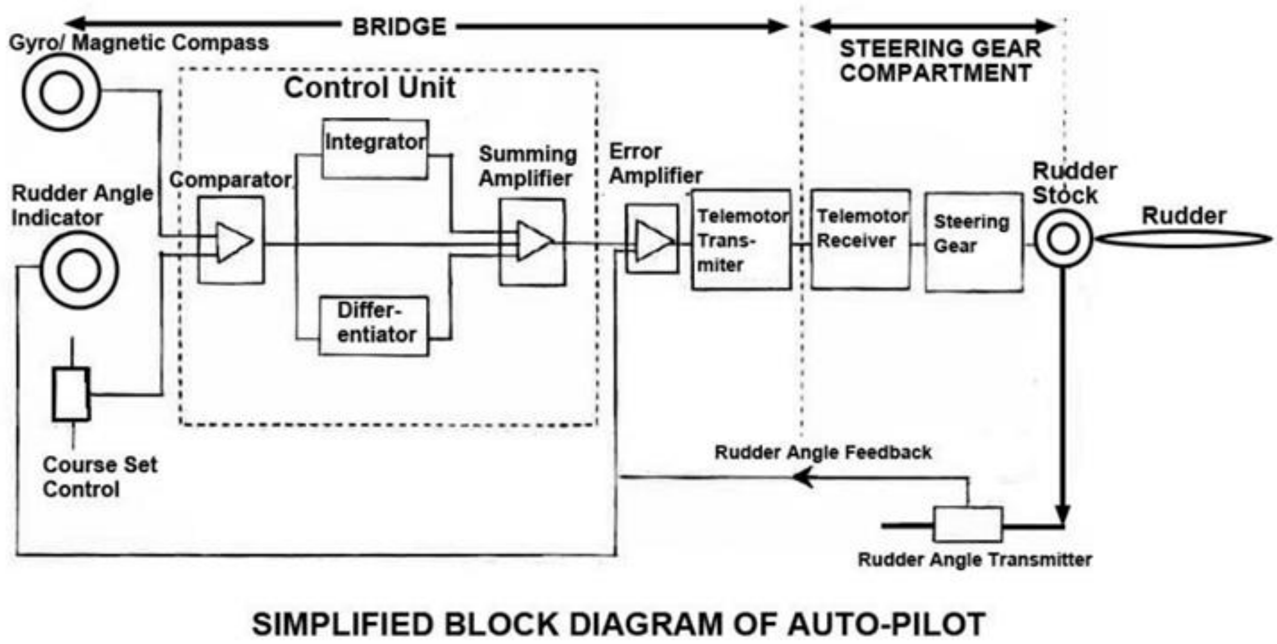

Fig. 1 - Simplified Block Diagram of an Auto-Pilot

The system shown above describes the operation of a steering system with an attached autopilot for a ship.
Trying to understand the choices of this combination of components in today's ships, we can deduce that it would be difficult for a ship's helmsman to concentrate and steer for an extended period of time if the ship had to steer a single course for an extended period of time. The autopilot performs the helmsman's duties by continually receiving feedback from the gyrocompass and directing the steering gear accordingly, ensuring that the ship steers the course established by the officer of the watch (OOW).
This not only spares the helmsman of steering tasks, but it is far more effective. When the ship deviates from its intended path, corrective action is promptly done, employing the appropriate amount of helm to return the ship to its intended direction.
This is accomplished by evaluating the course set by the OOW with the ship's Gyro compass heading; any discrepancy between the two results in an error, and corrective helm is given to the rudder.
As a result, the primary function of the autopilote included in the steering system is to control the course to be steered, which is determined by the course setting control know, while the ship's current heading is shown on the gyro or magnetic compass.

We will now look more specifically at the contribution of the various components in the system and their functionality through technical and physical characteristics:

Gyro Compass-Rudder, Angle Indicator, Course Set Control

The first block represents the ship's orientation and manoeuvring system, consisting mainly of the compass gyro, the rudder tiller indicator and automatic control of the actual course maintained by the ship.

These three systems work together, exchanging data and information via electromangnetic signals and electronic components. The gyro compass creates a reference system for the true direction and north taken, the rudder tiller indicator allows watchkeeping officers to check the correct and effective angle of rudder pitch during navigation, and the course control system is set up to control and respect the course planning made at the start, taking into account the distances covered and the way points on which to change it.

By analysing the three phisical components of this block in more detail, we can define their properties and characteristics:

Gyro Compass

Is a navigational equipment that employs a constantly operated gyroscope to precisely determine the direction of true (geographic) north. It seeks an equilibrium orientation under the combined influences of gravity and the daily rotation of the Earth. As a result, it is resistant to magnetic interferences induced by mineral deposits, steel buildings, or electric circuits.

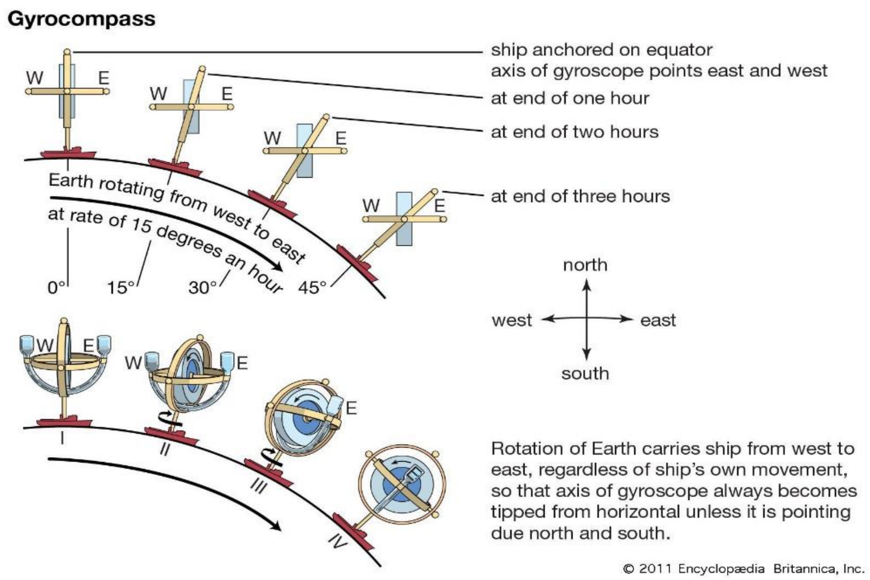

Fig. 2 – operating Gyrocompass with the Earth's rotation

The main disadvantages that could lead to the failure of the system are:

It is run with electrically, so when electricity fails gyro also fails. If the axle was out by more than 20 degree, then It might take 5 to 6 hrs to settle down but if its only 1 degree out, then it takes about 1/2 hr to settle down. When gyro compass stops for any reason , it will take some time to settle.

Rudder Angle Indicator

A device used to indicate the present position of the rudder blade, usually fitted in the wheelhouse, bridge wings and engine control room.

Fig.3 – Interface of the Rudder Angle Indicator

Consists of an analogue sensor (to prevent control being lost in the event of a total blackout of the ship's electrical and emergency systems) which indicates the position of the rudder in relation to its axis. The value cancels in the middle and shows in red and green respectively the angles of inclination of the rudder to starboard and port when turning the vessel around.

It is of considerable importance for understanding the exact position of the rudder, and in the event of problems it remains true to the actual position of the rudder. Used primarily as a verification system, if it fails, the main nature could be disconnection from the rudder shaft.

From the block diagram representation, the main connection of this component is with the last signal transmission element of the bridge: the Telemover. This connection makes it possible to transform the electromagnetic signal into a mechanical signal which actually moves the gears of the steering system.

Finally the analogue control will receive feedback on the actual and correct operation required of the rudder.

Course Set Control

Electronic device, such as a sensor, placed to verify the maintenance and change of course in the electronic planning related to the autopilot.

Its purpose is to process data in order to electronically check that the degrees of turn, tack and navigation are as originally set.

It is always combined with ECDIS and RADAR electronic charting systems in order to interact with them on the programmed departure information.

It receives data from the above and creates maintenance for them.

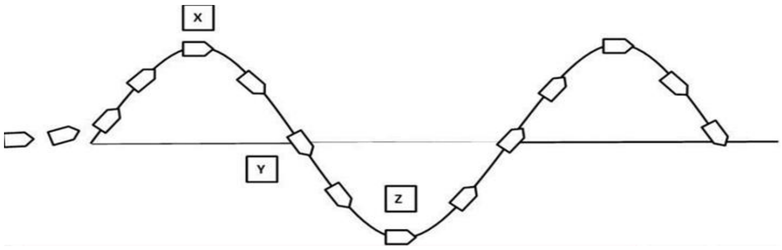

Fig. 9 – Course Set representation of trajectory

It also corrects the course from physical infenetimal effects and lends itself to being calibrated according to error.

Should it fail, the autopilot system would be compromised and not 100% effective. Does not lead to total system failure

Control Unit: Comparator, Integrator, Differentiator, Summing Amplifier, Error Amplifier

Next we look at the control unit, which consists of four basic components that link the course control systems seen earlier and the final part of the bridge which defines the intersection with the rudder gear systems.

Once the course planning has been set on the bridge, using a gyro compass, a comparator receives the signal and sorts it mainly to achieve a summing amplifier. The unit control, however, is shielded by two fundamental components in the transmission and control of the autopilot manoeuvring signal, the integrator and the differentiator. They have the task of operating simultaneously and increasing the quality of the transmission signal for the summing amplifier.

The gyro compass output is linked to the comparator in the control unit, together with the manual course setting control input signal.

Any difference between the gyro compass signal and the course setting signal generates an output error signal whose amplitude is proportional to the difference between the two signals, which is why the comparator is also known as proportional control.

In addition to the proportional control, the control unit has derivative (differentiator) and integral (integrator) controls for analyzing gyro or magnetic compass signals, as well as the course setting control. A summing amplifier is used to produce a resultant signal from these three controls (proportional, integral, and derivative), and the output of the error amplifier is supplied to the telemotor receiver in the steering gear compartment through the bridge's telemotor transmitter.

When the difference between the compass and the course setting signal is zero, no output is produced by the comparator. The output of the summing amplifier will also be 0, resulting in no rudder movement. The ship is on course under these conditions.

Finally, the terminal connection of this block will be through the transmission of the signal to a circuit that will analyse the input and level the transmission error, which will then be sequenced and transformed into a mechanical signal in the following steps

By analysing the five phisical components of this block in more detail, we can define their properties and characteristics:

Comparator

Comparators are devices that compare two voltages or currents and output a digital signal indicating which is larger. The output value of the comparator indicates which of the inputs is greater or lower. A comparator compares the two inputs applied to it and produces the comparison as the output. It has two analog input terminals and one binary digital output. They are commonly used in devices that measure and digitize analog signals, such as successive-approximation ADCs and relaxation oscillators.

Comparators are often used to check whether an input has reached a predetermined value.

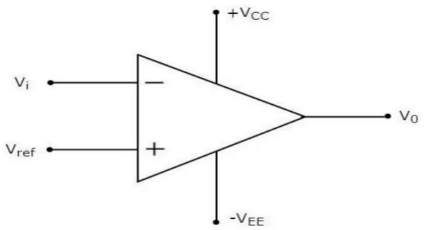

Fig. 5 – Comparator circuit.

Integrator

An electrical integrator is a type of first-order low-pass filter that may operate in either the continuous-time (analog) or discrete-time (digital) domain. An integrator has a low pass filtering effect, but when given an offset, it will collect a value and build it up until it meets a system limit or overflows.

It accumulates the input quantity over a defined time to produce a representative output.

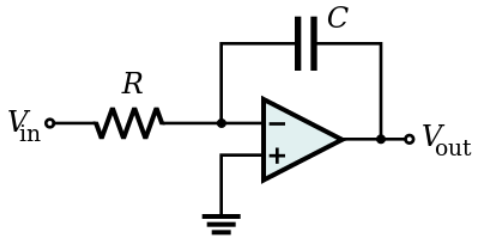

Fig. 6 – Integrator circuit.

Differentiator

A differentiator is a circuit that is designed such that the output of the circuit is approximately directly proportional to the rate of change (the time derivative) of the input. The differentiator circuit is essentially a high-pass filter.

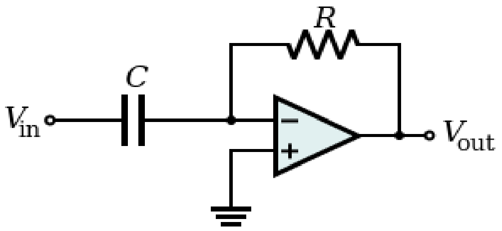

Fig 7 – Differentiator circuit.

Summing Amplifier

Another sort of operational amplifier circuit layout is the Summing Amplifier, which is used to integrate the voltages existing on two or more inputs into a single output value.

The objective is to include numerous sources of input while keeping each source distinct such that one of the input sources does not effect another.

Summing amplifiers are commonly used to process analog signals.

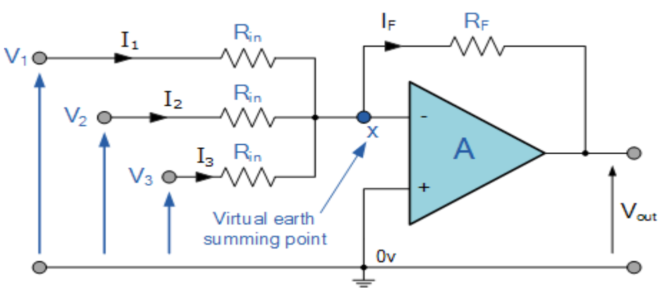

Fig. 8 – Summing Amplifier circuit.

Error Amplifier

An error amplifier is most typically seen in feedback unidirectional voltage control circuits, which compare the sampled output voltage of the circuit under control to a stable reference voltage. Any discrepancy between the two causes a compensatory error voltage to be generated, which tends to shift the output voltage closer to the design specification.

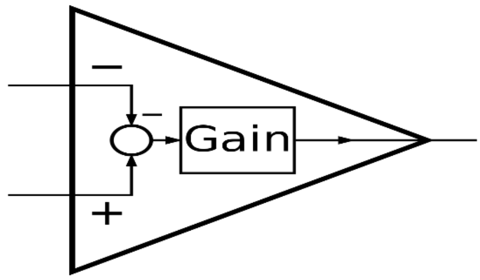

Fig. 9 – Error Amplifier circuit.

An error amplifier is a device that amplifies an erroneous signal. The disparity between a reference signal and the input signal causes this mistake. It can alternatively be regarded as the sum of the two inputs. Because of its self-correcting function, they are typically employed in conjunction with feedback loops**.**

Steering gear compartment: Telemotor Trasmitter, Telemotor Receiver, Steering Gear

This compartment is crucial for the transition from the field of transmitted electromagnetic signals and the actuation of the signal, by means of transforming systems such as the coupled Telemotor Transmitter-Receiver, into the pulse and mechanical movement of the steering system.

The telemotor is an hydraulic device by which the movement of the wheel on a ship's bridge operates the steering gear at the stern. Telemotor contains: Hydraulic transmitter, By-pass valve, Hydraulic receiver, Charging system

As mentioned above, once the signal has been sequenced by all the previous components, at its arrival there is a Transmitter which has the task of carrying out the crucial transmission of the signal, passing it to the Receiver which analyses it and recognises it as a mechanical imput to be passed to the steering gears and subsequently to the final transmission.

We will analize more specifically the physical characteristics and technical properties of these three components:

Telemotor Trasmitter

A telemotor transmitter is a hydraulic control system that consists of transmitter pipes and a charging device. The bridge houses the transmitter, which is incorporated into the steering wheel console, while the receiver is situated on the steering gear. The charging device is close to the receiver, and the system is charged with non-freezing fluid.

A refueling tank surrounds the rams in the transmitter, preventing air from entering the system. As the wheel reaches midships, a bypass between the two cylinders opens up. In addition, the supercharging unit produces pressure in the system at thae mid position, ensuring a quick reaction of the system to wheel movement. This supercharging machine also sucks in replenishing fluid if it is needed in the system and has a relief valve design in case the pressure becomes too high. Each major pipeline is equipped with pressure gauges and air vent cocks.

Telemotor Receiver

The receiver is made up of two receiving cylinders in one casting, with the circuit pipes linked to the outside end of each ram. Any fluid displaced in the transmitter cylinder by the piston will therefore be driven via the pipes and circuits valves to the receiving cylinders. The receiver rams are fixed in the arrangement, and any displacement of the fluid causes the cylinder body to move along the ram against the compression of one of the spings. When the helmsman releases the steering wheel, the compressed spring returns the receiver and, with it, the transmitter to midship position. The pump control is linked to one end of the cylinder body through the hunting lever.

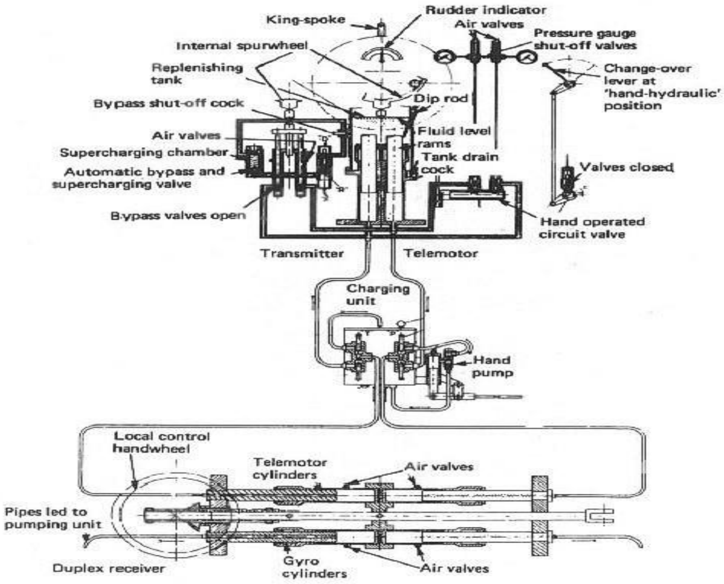

Fig. 10 – Telemotor and steering gear system.

Steering Gear

Rudders are the primary system for the ship's overall motion and control. However, keep in mind that the entire rudder movement is based on another essential mechanism known as the Steering Gear.

Steering Gear, in conjunction with the rudder system, specifies the whole 'turning mechanism' required for all ships, regardless of size, kind, or operation.

Since the very first ships, which were steered by hand, the steering gear system has been an essential aspect of the ship's equipment.

The major control of any ship's steering operations is delivered from the helm, similar to how the complete control of the vehicle's "steer-ability" resides on the driver's steering wheel. The 'control force' for turning is released from the steering wheel at the helm, and it reaches the steering gear system.

The steering gear system produces torsional force on a certain scale, which is subsequently passed to the rudder stock, which spins the rudder. A contemporary ship's intermediate steering systems can be complex, with each minor component serving a specific purpose. We do not go into depth about each of these components.

In response to a signal from the bridge, the steering gear moves the rudder. The whole system is composed of three components: control equipment, a power unit, and a transmission to the rudder stock. The control equipment receives a signal from the bridge indicating the required rudder angle and operates the power unit and transmission system until the desired angle is obtained.

When necessary and with quick effect, the power unit delivers the force to move the rudder to the correct angle. The steering gear, or transmission system, is the mechanism that allows the rudder to move.

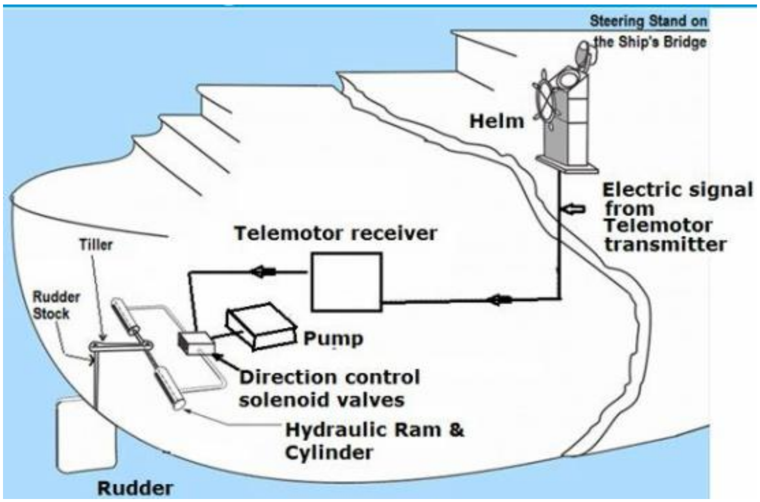

Fig. 11 – Signal being computed from the telemotor to the actuation of the steering gear

Terminal components: Rudder Stock, Rudder, Rudder Angle Trasmitter

Once the components and the operation of the rudder gears have been defined, the mechanical movement is transmitted to the final system temrinal: consisting mainly of rudder stock, rudder and rudder angle transmitter.

In this case the rudder stock receives the mechanical movement, via a series of suitably calibrated couplings and gears, from the steering gear, which then acts as the initial terminal for the motion and rotation of the rudder around its vertical axis. The movement of the rudder determines the turn and direction of the ship as it is planned, and the cycle of operation is completed by a control system which transmits feedback directly from the rudder to the control cabin/engine room regarding the actual direction and inclination of the rudder. This signal ends when the rudder angle indicator is reached.

Rudder Stock

A vertical shaft that transmits the steering gear's turning force to the rudder blade. The rudderstock will be composed of forged steel. Connection to the rudder blade is given by hydraulic cone fit, while connection to the tiller or actuator is provided by hydraulic cone fit, a key connection, or clamping rings for smaller rudders.

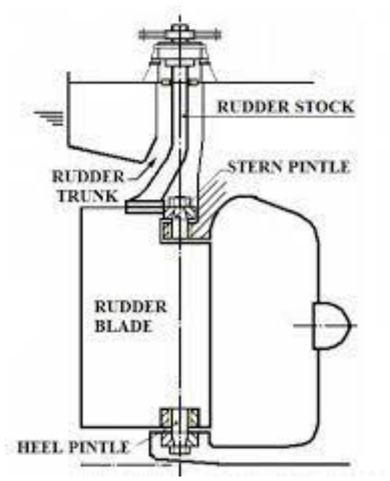

Fig. 12 – Rudder stock connected to the rudder blade

Rudder

It is a component of a boat or ship's steering equipment that is attached outside the hull, generally near the stern. The most typical design consists of a virtually flat, smooth surface of wood or metal attached to the sternpost at its forward edge. It works on the basis of differential water pressures. When the rudder is rotated such that one side is more exposed to the force of the water flowing past it than the other, the stern is forced away from the side on which the rudder is turned, and the boat swerves away from its original direction. The rudder on bigger boats is turned by hydraulic, steam, or electrical equipment.

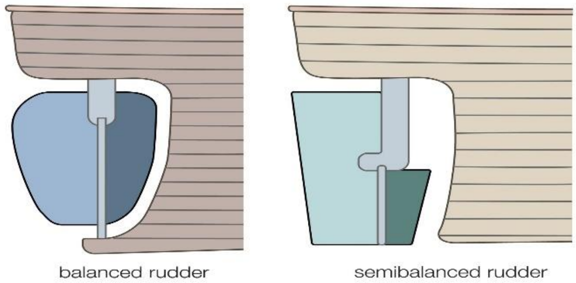

Fig. 13 – Types of rudder for ship's steering equipment

Rudder Angle Trasmitter

A Rudder Angle Transmitter is a Rudder Angle Transducer that provides steering feedback. It communicates the vessel's Rudder Angle to a Marine Data Rudder Angle Indicator, which is mounted in the steering cabin. More specifically indicate the present position of the rudder blade, usually fitted near the Ship's wheel on the bridge and in the engine control room.

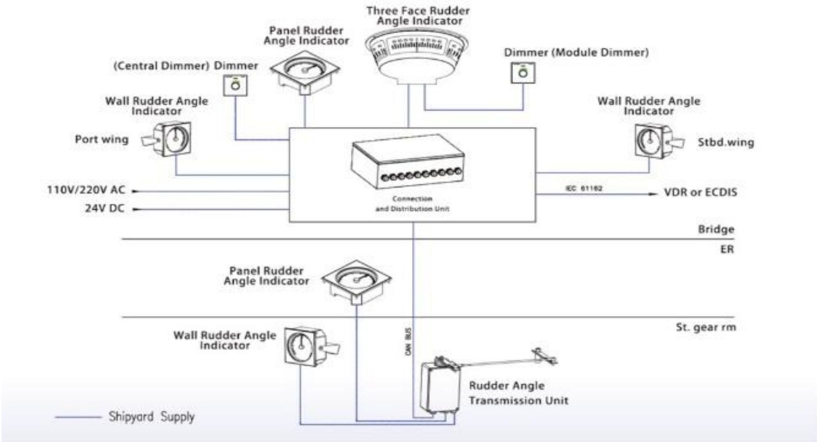

Fig. 14 – Electronical Unit of ther Rudder Angle Transducer

FMEA (Failure Mode and Effects Analysis)

In order to study and correct potential failures on our system it is absolutely important to run an FMEA. This procedure is a bottom-up process for discovering and correcting design deficiencies through the analysis of potential failure modes, effects, followed by a recommendation of corrective action. For this system, the components identified previously have been examined studying their potential failure modes, their effects and the causes of these failures. These examinations provide critical and necessary information regarding the safety, quality and reliability of the entire system analysed. It also under lights the potential failure modes that might result in sever effects such as the complete failure of the entire components chain.

In this study we decided to also include the criticality of the failures analysing by means of severity, occurrence and detectability. These parameters have been attributed studying the interactions between the components of the system. For these parameters three numbers from 1 to 10 have been identified to assess the potential effects of the failure. At the end these numbers have been put together to study the overall risk of failure by introducing the risk priority number (RPN) which is the product of severity, occurrence and detection:

$$RPN = S * O * D$$

Since these three factors are assigned rankings from 1 to 10, the RPN is in the range between 1 and 1000. The higher the RPN value, the higher the risk of failure.

In this FMEA have also been included actions such as design change, material upgrade, and revision of test plans. For this analysis an Excel sheet has been created and filled with each component and everything that regards their possible failures. The tables have been divided in several

Process Step/Input	Potential Failure Mode	Potential Failure Effects	SEVERITY (1 - 10)	Potential Causes	OCCURRENCE (1 - 10)	Current Controls	DETECTION (1 - 10)	RPN	Action Recommended to reduce the Occurrence	Resp.	Actions Taken	SEVERITY (1 - 10)	OCCURRENCE (1 - 10)	DETECTION (1 - 10)	RPN	
What is the process step, change or feature under investigation?	In what ways could the step, change or feature go wrong?	What is the impact on the customer if this failure is not prevented or corrected?		What causes the step, change or feature to go wrong? (how could it occur?)		What controls exist that either prevent or detect the failure?			What are the recommended actions for reducing the occurrence of the cause or improving detection?	Who is responsible for making sure the actions are completed?	What actions were completed (and when) with respect to the RPN?					
Gyro / Magnetic Compass	Deviations from the axis	Navigation system might work improperly	6	Rapid changes in course, speed and/or latitude	3	Control Unit detection	2	36	Regular maintanence	Inspection Crew	Waiting some time depending on the severity of the deviation	6	3	2	36	1st Bridge Block
	Electrical failure	Sudden failure of cabled connection	8	Unexpected causes depending on the device lifetime	3	Control Unit detection	2	48	Regular maintanence	Inspection Crew	Replacement of the faulty connection	8	3	2	48	
	General failure of the system	Sudden failure	8	System reaching its wear-out	3	Control Unit detection / Visual detection	2	48	Regular maintanence	Inspection Crew	Replacement of the compass	8	3	2	48	
Rudder Angle Indicator	Electrical failure of feedback and amplifier unit	No feedback on the position of the rudder	6	Electrical failure in the internal system	2	Control Unit detection	2	24	Regular maintanence	Crew Engineers	Repair / change of the faulty indicator	6	2	2	24	
	Mechanical failure	The indicator stops to show the direction of the rudder	4	Mechanical components in the system brake	3	Visual detection	3	36	Regular maintanence	Crew Engineers	Substitution / repair of the mechanical component	4	3	3	36	
Control Set System	Electronical failure	The course doesn't correspond with the original auto-pilot course	7	Failure of the sensor that calculates the navigation course	4	Control Unit detection	2	56	Reliable manufacturing of the system	Crew Engineers	Requires a deep inspection to correct the data processing	7	4	2	56	

Fig. 15 – FMEA for the 1st Bridge Block

These tables shows the failure mode and their analysis for the 1st bridge block. In this case, it was studied that the potential occurrence of these failures is not too elevated and that the detection factor, given by the Control Unit, is not high either considering how the internal unit that computes eventual error is to be considered reliable in the case of a faulty component. The entire block can be regarded as not strictly necessary for the manoeuvrability of the ship but it's obvious how without these indicators, the auto-pilot has absolutely no feedback on the trajectory of the ship and the boat itself would be completely un-manoeuvrable.

Comparator	Failure comparing the input signals	The difference identified that goes through the unit control is not correct	10	Wrong input signal calculation and consequent incorrect comparison	3	Control Unit detection	4	120	Correct equipment calibration and use	Electrical Engineers	Replacement or recalibration of the device	10	3	4	120	Control Unit
Integrator	Failure filtering the signal when given an offset	The summing amplifier will receive an unwanted signal	8	Wrong operation within the analog or digital domain	2	Control Unit detection	4	64	Correct equipment calibration and use	Electrical Engineers	Replacement or recalibration of the device	8	2	4	64	
Differentiator	Failure filtering the signal when given an offset	The summing amplifier will receive an unwanted signal	8	Wrong operation within the analog or digital domain	2	Control Unit detection	4	64	Correct equipment calibration and use	Electrical Engineers	Replacement or recalibration of the device	8	2	4	64	
Summing Amplifier	Integration from the 3 input signals into 1 fail	The output signal obtained is not correct and the telemotor will compute a completely different information	10	If the device's integration is not correct, each input signal might affect the other interfering with the calculation of the output signal.	3	Electronical feedback devices on the bridge	3	90	Correct equipment calibration and use	Electrical Engineers	Replacement or recalibration of the device	10	3	3	90	

Fig. 16 – FMEA of the Control Unit

The analysis on the Control Unit is crucial. In this system any kind of failure related to the control unit leads to a complete failure of the entire auto-pilot. Therefore, the severity factor has been attributed with a thought regarding this; it's possible to observe how the RPN values are already slightly higher than the 1st bridge block. The components that are included in this block are highly electronical and any failure leads to a necessary complete replacement of the faulty device.

Error Amplifier	The integration calculation of the amplifier and the compensatory error is not generated/computed properly	The output signal is not correct and the telemotor will compute a wrong signal	9	Faulty error amplifier and/or calculation error	4	Electronical feedback devices on the bridge	3	108	Correct equipment calibration and use	Electrical Engineers	Replacement or recalibration of the device	9	4	3	108	Amplifier Unit Block
	The reference input signal is not correct, therefore the output signal is not the one requested	The output signal is not correct and the telemotor will compute a wrong signal	9	The reference signal is not correct	6	Electronical feedback devices on the bridge	3	162	Correct equipment calibration and use	Electrical Engineers	Replacement or recalibration of the device	9	6	3	162	

Fig. 17 – FMEA for the Amplifier Unit

The error amplifier also plays a crucial role in the system we're studying since it's objective is to compute the previous signal from the control unit and send an output signal to the telemotor. Any error or disturbance within the signal will be amplified and a chain reaction might induce unwanted controls through the telemotor and the steering gear system that will let completely out of control the ship.

Telemotor Transmitter	The signal from the error amplifier does not reach the transmitter	The transmiter can't compute nor send the right signal to the receiver	8	Electronical error within the system	3	Control Unit on the bridge	3	72	Quality manufacturing and calibration of the system can reduce the occurrence	Electrical Engineers	Replacement or recalibration of the device	8	3	3	72	Telemotor Unit Block
	The signal arriving to the receiver is incorrect	The signal arriving to the receiver is incorrect	8	Loss of signal or incorrect computing between the transmitter and the receiver	3	Feedback system on the receiver	3	72				8	3	3	72	
Telemotor Receiver	Hydraulic ram & cylinder system doesn't work	The charging device is not activated or works improperly	7	Mechanical failure, leakage and/or signal error	3	Mechanical failure, requires a thourough check inside the mechanism	5	105	Correct manufacturing and installation of the gearing system	Machinists	Repairing or replacement of the mechanical system	7	3	5	105	
	Bypass valve stops working	Loss of control from the bridge wheel compartment	8	Overpressure/leakage in the pipeline and/or rupture	3	It's also a mechanical failure	4	96	Correct choice of the valve and correct input	Machinists	Repairing or replacement of the mechanical system	8	3	4	96	
	Pump failure	No more control over the hydraulic ram	7	No power from the main or emergency generator / rupture in the pump's system	5	Mechanical failure	4	140	Correct choice of the pump and the system that connects it to the hydraulic ram	Machinists	Repairing or replacement of the mechanical system	7	5	4	140	

Fig. 18 – FMEA for the Telemotor Unit

The telemotor unit oversees transforming an electrical analog input signal into an actuation for the steering gear that will then transport the movement to the rudder blade. It's important to consider the severity and the possible occurrence of these failures since they are necessary to consider in order to have a properly working steering gear that will respond in the correct way to the impulse of the telemotor itself.

Steering Gear	Control equipment failure	The system's input for the rudder's stock will be wrong	7	Incorrect input from the telemotor receiver is not responding like the helm's wheel is required to	3	Control Unit detection	2	42	Correct equipment calibration and use	Electrical Engineers	Accurate check of the entire steering gear system in order to find the faulty component and replace it	7	3	2	42	Steering Gear Compartment
	Power unit failure	Electrical power loss in the steering gear	9	Incorrect input from the telemotor receiver is not responding like the helm's wheel is required to	3	Control Unit detection	2	54	Using the right cabled connections and a regular maintenance can lower the occurrence	Electrical Engineers	Replacement of the faulty supplying power system or maintenance	9	3	2	54	
	Transmission failure	The rudder steering actuation stops to work and the input signal doesn't produce na effective behaviour	7	Mechanical failure in the gearing mechanism	5	Mechanical geared coupling failure	5	175	Manufacturing or acquiring correct gears in order to keep a stable reliability in this system is absolutely necessary	Mechanical Engineers	In-depth research of the issue is required since even the slightest faulty coupling can produce the failure studied	7	5	5	175	
Rudder Stock	Rupture of the steering gear hydraulic cone fit connected to the tiller	Damage on the steering gear and/or rudder blade	8	Coupling breaks due to wearing or potential fatigue loads	3	Visual Inspection	5	120	Correct choice of the coupling in terms of loads and enviroment conditions	Machinists	Repair or full repair of the broken connection and refitting of the rudder stock	8	3	5	120	
	Stern and/or heel pintles break	Loss of control on the rudder blade	7	Coupling on the pintles not corrctly designed or fatigue loads	5	Visual Inspection	4	140	Correct choice of the coupling in terms of loads and enviroment conditions	Machinists	Repair or full repair of the broken connection and refitting	7	5	4	140	
Rudder Blade	Mechanical failure of the component	Potential loss of the rudder	9	Fatigue failure of the rudder	3	Visual Inspection	3	81	Use of proper material, correct design and installation can reduce the occurrence of the failure	Crew Engineers	Replacement of the broken rudder	9	3	3	81	

Fig. 19 – FMEA for the Steering Gear Compartment

The steering compartment is of course mandatory. Its reliability is necessary in order to obtain the wanted objective which is the eventual turning of the rudder blade in the case of a change of trajectory in the autopilot memory. Most of the components here are mechanical and for this reason a potential failure is easier to replace but much harder to identify since even the slightest bearing and leakage may cause a failure that would persist in the system.

Rudder Angle Transmitter	Electronical failure	No feedback on the current rudder's position	6	Electronical and signal computing failure	4	Control Unit detection	3	72	Correct calibration of the transducer	Electronical Engineers	Replacement of the transducer	6	4	3	72

Fig. 20 – FMEA for the Rudder Angle Transmitter

Severity Scale:

Effect	Criteria: Severity of Effect	Ranking
Hazardous - Without Warning	May expose client to loss, harm or major disruption - failure will occur **without** warning	10
Hazardous - With Warning	May expose client to loss, harm or major disruption - failure will occur **with** warning	9
Very High	Major disruption of service involving client interaction, resulting in either associate re-work or inconvenience to client	8
High	Minor disruption of service involving client interaction and resulting in either associate re-work or inconvenience to clients	7

Moderate	Major disruption of service not involving client interaction and resulting in either associate re-work or inconvenience to clients	6
Low	Minor disruption of service not involving client interaction and resulting in either associate re-work or inconvenience to clients	5
Very Low	Minor disruption of service involving client interaction that does not result in either associate re-work or inconvenience to clients	4
Minor	Minor disruption of service not involving client interaction and does not result in either associate re-work or inconvenience to clients	3
Very Minor	No disruption of service noticed by the client in any capacity and does not result in either associate re-work or inconvenience to clients	2
None	No Effect	1

Occurrence scale:

Probability of Failure	**Time Period**	**Per Item Failure Rates**	**Ranking**
Very High: Failure is almost inevitable	More than once per day	>= 1 in 2	10
	Once every 3-4 days	1 in 3	9
High: Generally associated with processes similar to previous processes that have often failed	Once every week	1 in 8	8
	Once every month	1in 20	7
Moderate: Generally associated with processes similar to previous processes which have experienced occasional failures, but not in major proportions	Once every 3 months	1 in 80	6
	Once every 6 months	1 in 400	5
	Once a year	1 in 800	4
Low: Isolated failures associated with similar processes	Once every 1 - 3 years	1 in 1,500	3
Very Low: Only isolated failures associated with almost identical processes	Once every 3 - 6 years	1 in 3,000	2
Remote: Failure is unlikely. No failures associated with almost identical processes	Once Every 7+ Years	1 in 6000	1

Detection Scale:

Detection	**Criteria: Likelihood the existence of a defect will be detected by process controls before next or subsequent process, -OR- before exposure to a client**	**Ranking**
Almost Impossible	No known controls available to detect failure mode	10
Very Remote	Very remote likelihood current controls will detect failure mode	9

Remote	Remote likelihood current controls will detect failure mode	8
Very Low	Very low likelihood current controls will detect failure mode	7
Low	Low likelihood current controls will detect failure mode	6
Moderate	Moderate likelihood current controls will detect failure mode	5
Moderately High	Moderately high likelihood current controls will detect failure mode	4
High	High likelihood current controls will detect failure mode	3
Very High	Very high likelihood current controls will detect failure mode	2
Almost Certain	Current controls almost certain to detect the failure mode. Reliable detection controls are known with similar processes.	1

Faulty Tree Analysis (FTA)

Fault tree analysis is one of numerous symbolic "analytical logic approaches" that may be found in operations research and system dependability. Reliability block diagrams are another option (RBDs).

Fault tree diagrams are logic block diagrams that show the state of a system (top event) in terms of its components' states (basic events). Fault tree diagrams, like reliability block diagrams (RBDs), are graphical design techniques that give an alternate methodology to RBDs.

An FTD is constructed from the top down and in terms of events rather than blocks. It employs a graphical "model" of the system paths that might lead to a predicted, unpleasant loss occurrence. Using common logic symbols, the paths connect contributing events and situations (AND, OR, etc.). A fault tree diagram's essential structures are gates and events, where events have the same meaning as a block in an RBD and gates are the conditions.

The most fundamental distinction among fault tree diagrams and RBDs is that in an RBD, you operate in the "success space," but in a fault tree, you work in the "failure space." To put it another way, the RBD considers success combinations, whereas the fault tree considers failure combinations. Furthermore, fault trees have historically been used to examine fixed probabilities, but RBDs may incorporate time-varying ranges for the success or failure of the blocks, as well as additional features including such repair/restoration distributions.

Types of Fault Tree Analysis

The standard Fault Tree Analysis approach is not the only one available. Other FTA extensions have been created for specific use cases and sectors. The additions would be able to visualize characteristics that are difficult to convey using traditional fault trees.

In general, FTAs are classified as either qualitative or quantitative.

When you know the probability of the events in your fault tree, you may do quantitative analysis as an add-on. Let's go through each of them in further detail.

Qualitative FTA

Qualitative FTA is used to obtain knowledge about the structure of fault trees in order to assess system vulnerabilities. There are several approaches to qualitative fault tree analysis, including:

Minimal cut sets (MCS) aid in identifying a system's weaknesses. If an FT has a small number of components or a collection of pieces with a high failure rate, the system is considered unreliable. MCS recognizes these groups of items in a fault tree. If you can lower the likelihood of particular components failing or create redundancies, you will increase the system's dependability.

Minimal path sets (MPS) will assist you in determining a system's resilience. It attempts to discover the bare minimum of components required to keep the system running. After you've identified those factors, you may spend time attempting to reduce the likelihood of their failing. This improves the system's overall dependability.

Common cause failures (CCF) establish if a single factor may cause many failures. CCF-identified components are regarded as important components. Your team must ensure that these components are examined and changed on a regular basis (as necessary).

Quantitative FTA

Quantitative FTA could be used to evaluate the real likelihood of the failure under consideration. Assigning a numerical failure probability will assist you in better understanding and prioritizing your risk.

The outcome of quantitative FTA might take the form of stochastic or significance measures:

Stochastic measurements indicate the system's failure likelihood.

Relevance measurements ascribe the importance of a cut set or path to the overall system's dependability.

You may simply compute the odds of your intermediary ’s reliance on the gates that join them once you know the probabilities of your fundamental events. AND gates and OR gates are the most commonly used gates.

Practical Example of FTA

If one or more of the minimal cut sets occur, the top unwanted event happens, hence the key goal is to discover minimal cut sets. Furthermore, assuming all of the smallest cuts are independent of one another, we may determine the probability of the top unfavourable event by:

$$P_0(t) = 1 - \prod_{j=1}^{k} \left[1 - P_j(t)\right]$$

P_j denotes the failure probability of the minimal cut set.

The following are the primary benefits of FTA: The fault tree graphically depicts the analysis that will assist the team in working on the source of the event in a logical manner that leads to failure, as well as highlighting the essential components associated to system failure.

Gives an efficient way for analyzing the system; unlike other methods of analysis, human mistakes are included in the study; it aids in the prioritization of action items to fix the problem; and it provides qualitative and quantitative analysis.

In terms of disadvantages, the FTA has too many gates and events to consider for large system analysis. The primary disadvantage is that it examines only one top event, common cause failures are not always obvious, time related and other delay factors are difficult to capture, and experienced individuals are required to understand the logical gates.

In our case we used and introduced software called FTA TopEvent, which best represented the components represented in our system and allowed us to understand the logical progression of the system by progressing through the cause and effect of the individual components, weighted according to their use and their technological function.

The results obtained are as follows:

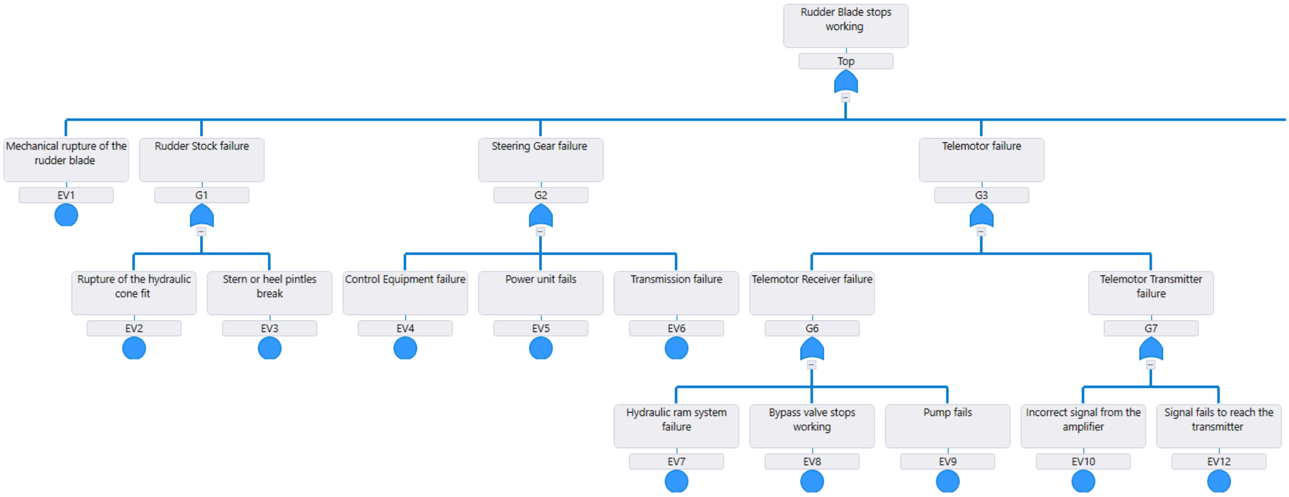

Fig. 21 – Left half of the FTA

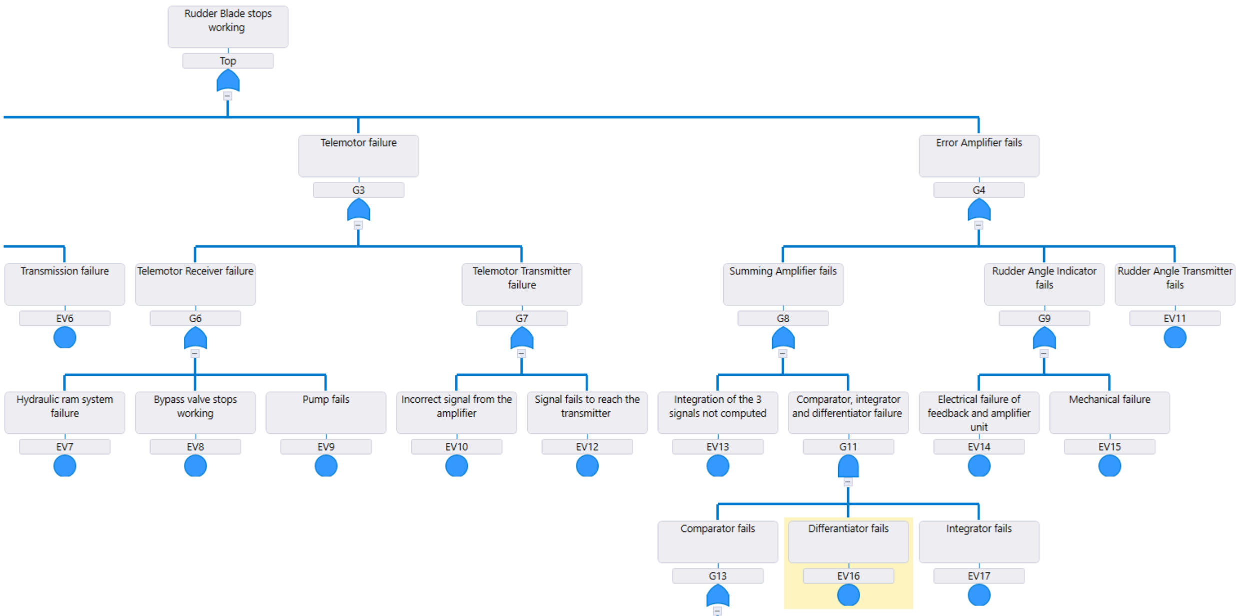

Fig. 22 – Right part of the FTA

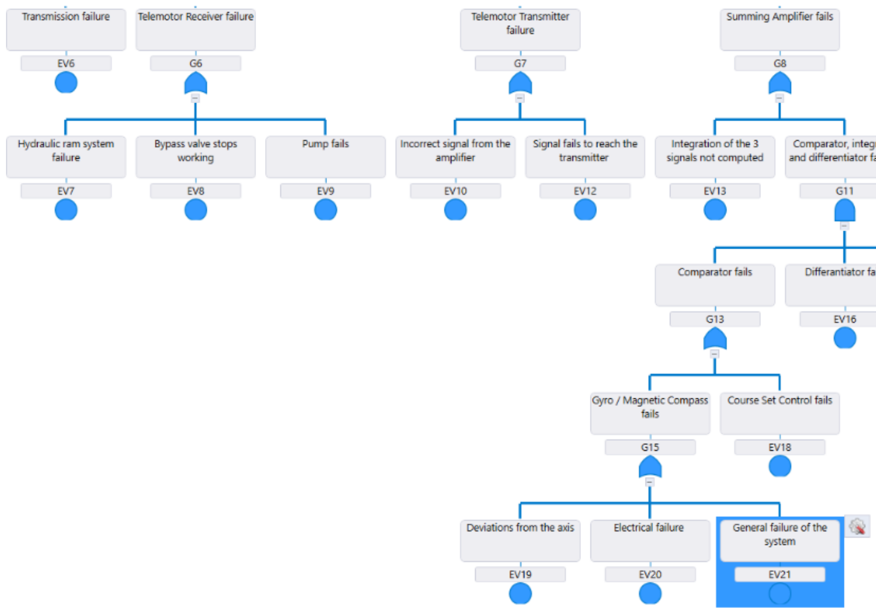

Fig. 23 – Bottom part of the FTA

CONCLUSIONS

This project has the objective of analysing and decomposing a system of any kind and underlighting the failure modes of each component interested. Since the autopilot system of a ship is an extremely intricate and developed system between electronical and mechanical components, most of the failures analysed in this report will lead to a potential waterfall effect that will affect the entire system. In other words, very few components lead to a partial failure of the system since any error that will be perpetrated in each block will then be translated into a motion of the rudder blade that will be proportionate to the error itself.

In general, the RBD diagram identified at the beginning of the paper is identified by a series-type of connection between the components apart from few ones such as the retroaction that describes the transmitter's feedback on the error amplifier. This leads to using the OR logic port in most of the fault trees that identifies the system.

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