Functional Analysis Report

Work Package 3 – Deliverable 3.2

Delivery date of the deliverable: 30/09/2014

Lead organisation for this deliverable
IFREMER

Lead authors: Jean-François Rolin

Contributors: Loïc Quemener, P.Jegou, Laurent Delauney, Blas J. Galván, Adriel S. Marco

Credit : GROOM FP7 project

THE OCEAN OF TOMORROW

COOPERATION

NeXOS - Next generation Low-Cost Multifunctional Web Enabled Ocean Sensor Systems Empowering Marine, Maritime and Fisheries Management, is funded by the European Commission's 7th Framework Programme - Grant Agreement Nº 614102

Deliverable 3.2 – Functional analysis report

Project Acronym: NeXOS

Project Title: Next generation Low-Cost Multifunctional Web Enabled Ocean Sensor Systems Empowering Marine, Maritime and Fisheries Management**.**

Programme: The Ocean of Tomorrow 2013 – 7th Framework Programme

Theme 2: Food, Agriculture and Fisheries, and Biotechnology
Theme 4: Nanosciences, Nanotechnologies, Materials and new Production Technologies
Theme 5: Energy
Theme 6: Environment (including climate change)
Theme 7: Transport (including aeronautics)

Topic: OCEAN.2013-2 Innovative multifunctional sensors for in-situ monitoring of marine environment and related maritime activities

Instrument: Collaborative Project

Deliverable Code: 140930_NXS_WP3_D.3.2-V.1.1

Due date: 30/09/2014

DOCUMENT HISTORY		
Edit./Rev.	*Date*	*Name*
Prepared	25 09 2014	Jean-François Rolin
Checked	27 05 2014	Christoph Waldmann
Approved	29 09 2014	Project Coordinator

DISSEMINATION LEVEL	
PU: Public	
PP: Restricted to other programme participants (including the Commission Services)	X
RE: Restricted to a group specified by the consortium (including the Commission Services)	
CO: Confidential, only for members of the consortium (including the Commission Services)	

DISTRIBUTION LIST

Copy no.	*Company / Organization (country)*	*Name and surname*
1	PLOCAN (ES)	Eric Delory, Ayoze Castro
2	IFREMER (FR)	Jean-Francois Rolin, Jerome Blandin, Laurent Delauney, Patrice Woerther
3	UNI-HB (DE)	Christoph Waldmann, EberhardKopiske
4	52-N (DE)	SimonJirka, MatthesRieke
5	AMU (FR)	Madeleine Goutx, Marc Tedetti,
6	UPC (ES)	Joaquín del Río, Daniel Mihai Toma
7	ACSA (FR)	Yann Le Page, FrédéricFiquet, François-Xavier Demotes-Mainard, Dorothée Coulomb
8	UNOL (DE)	Oliver Zielinski, RohanHenkel, Daniela Voß
9	NKE (FR)	PatriceBrault, DamienMalardé, Arnaud David
10	TRIOS (DE)	RüdigerHeuermann
11	CMR (NO)	David Peddie
12	CTN (ES)	Noelia Ortega, Pablo Ruiz, Daniel Alonso
13	HZG (DE)	Wilhelm Petersen, Steffen Assmann, RüdigerRoettgers, Frank Carsten
14	REC (NO)	Nils Roar Hareide, KarstenKvalsund
15	NIVA (NO)	Lars Golmen, KaiSørensen
16	SMID (IT)	Luigi Corradino
17	FRANATECH (DE)	Michel Masson, Joaquim Schwerdtfeger
18	UNIRESEARCH (NO)	SveinØsterhus
19	CNR-ISMAR (IT)	Marco Faimali, StefaniaSparnocchia, Giovanni Pavanello, MichelaMartinelli
20	IEEE (FR)	Jay Pearlman, Francoise Pearlman, René Garello
21	ECORYS (NL)	Johan Gille, Dick Mans

Objectives
Establish functional specifications from previous experience and Nexos objectives of robustness and efficiency

Description of Work
Task 3.1

Input needed
▪ D1.3: Project implementation plan ▪ D3.1 Technology Readiness Level report

Task work plan

NeXOS TASK 3.1 FROM THE DESCRIPTION OF WORK

Objectives

Evaluate the technological maturity of sensor systems

Description of Work

Associated Task 3.1. Engineering specifications and technological maturity; Leader: IFREMER; Duration: M6-M12

The target specifications developed as part of WP 1 will determine the required performance in precision, deployment duration etc of the new sensors. The Technology Readiness Level (TRL) will be evaluated for each of the NeXOS sensor systems, leading to basic engineering specifications so that performance can be demonstrated within the duration of the project. The TRL study will use remote interviews and meetings among the NeXOS consortium (including referenced providers) and related projects (EuroARGO, EMSO/ESONET, JERICO, GROOM, etc). It will be based on common practice for sensor choice and enhancement and will critically review the limits and achievements of existing sensors (comparable to what will be developed in NeXOS) within the market. In parallel to WP5, 6 and 7, this task will perform functional analysis for several multi-sensor architectures and integration scenarios (including multiparameter probe, junction boxes, profilers and gliders as well as new concepts). The analysis will address the following questions:

Is it possible to integrate additional sensors into the NeXOS sensor package?

• what is the feasibility of self calibration and/or self biofouling control?

• can pre-processing and modifications to sampling procedure be applied locally?

• How the RAMS strategy can contribute to the production of more reliable and cost-efficient sensors ?

Inputs needed

Deliverable D.1.3: Project implementation plan

D3.1) TRL report: The Technology Readiness Level will be evaluated for each of the NeXOS sensor systems, leading to basic engineering specifications so that performance can be demonstrated within the duration of the project. This deliverable will justify part of the work done in task 3.1 [M6]

Acknowledgements

Funding for the NeXOS project (Grant Agreement No. 614102) was received from the EU Commission as part of the 7th Framework Programme, "The Ocean of Tomorrow" .

The help and support, in preparing the proposal and executing the project, of the partner institutions is also acknowledged:PlataformaOceánica de Canarias (ES), InstitutFrançais de Recherche pour l'Exploitation de la Mer (FR), Universität Bremen (DE), 52°North Initiative for Geospatial Open Source Software GmbH (DE), Aix Marseille University (FR), UniversitatPolitècnica de Catalunya (ES), Architecture et Conception de SystèmesAvancés (FR), Carl von Ossietzky Universität Oldenburg (DE), NKE Instrumentation (FR), TriOSMEss- und Datentechnik GmbH (DE), Christian Michelsen Research AS (NO), Centro Tecnológico Naval y del Mar (ES), Helmholtz-ZentrumGeesthachtZentrum fur Material-und Kustenforschung GmbH (DE), RundeMiljøsenter AS (NO), NorskInstitutt for VAnnforskning (NO), SMID Technology s.r.l. (IT), Franatech AS (NO), Uni Research AS (NO), ConsiglioNazionaledelleRicerche (IT), IEEE France Section (FR) and ECORYS Nederland BV (NL).

Table of contents

1 Executive Summary

Within NeXOS project, methods have been prepared to design according to Technology Readiness and Reliability indicators. Such approach suffers usually from lack of input in oceanography.

We review eight technologies associated to NeXOS because they are developped in the project, are mentionned in the use cases or at least will be used during the demonstration (WP9). This provides a basis for next WP3 activities which will lead to Reliability and Cost studies (D3.5, D3.6).

The comprehensive and innovative fouling protection system (Task 3.2 and 3.3) opens the way to quantify and compare Maintainability performances. We can see several interesting system analysis to be performed on the fouling protection. provide keys to open major technological locks:

- Prepare the way to avoid the intervention of an expert in real time to check that biofouling protection is sufficient.
- Open the way to triggering from a fouling preventing technology to a curative one (same as the preventive with more intense action or additional curative technique such as wiper or waterjet).
- Open the way to redundancy or other improvement issued from system analysis.
- Optimize fouling protection energy consumption.

Final aim is to reach the maximum sensor operation duration without maintenance given a biological activity in a site.

Thanks to previous studies by GROOM FP7 Design Study project, we were able to analyse reliability for the gliders as vehicles. This is promising in order to help the NeXOS designs associated with gliders and help making decisions on the problem of the optimum sensor per vehicle.

Such system analysis will be applied to the sensor issues for instance on Argo and coastal profilers.

Maintenance issues will be addressed starting with a life cycle analysis and the collection of data on faults. The opportunity of redundancy will be proposed.

We will use fixed platforms to advance towards providing reliability figures as WP4 tasks on smart sensors open the way to analyze all the aspects of sensor to observatory link such as re-usability, interoperability, software open source.

2 Introduction

The system engineering approach of NeXOS (Figure 1) allocates a crucial role to WP3.

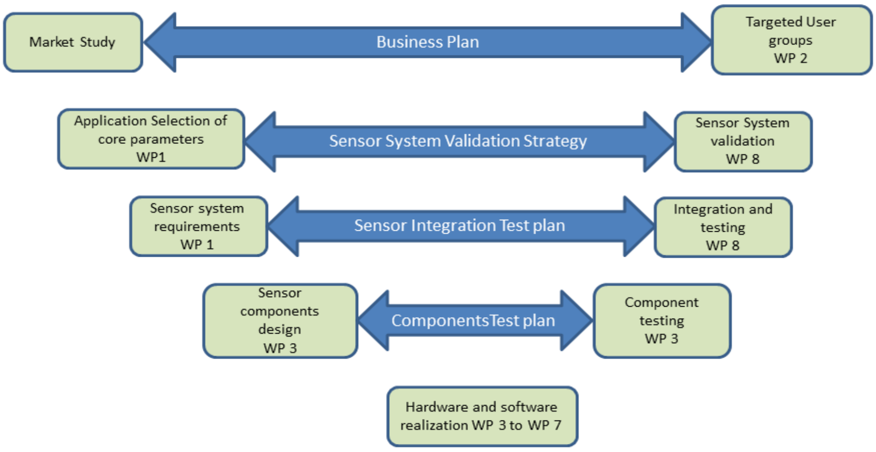

Figure 1- The V-diagram describing the steps in the development process

In the V shape approach, WP3 deals with sensor components design and testing and more generally with a better understanding of functions in order to be able to perform system analysis when needed.

The scope of this work package could be understood as extremely large, covering all sensors, platform, operational or research data collecting systems. We will avoid a wide ranging cumbersome approach to focus on the critical aspects or those where improvement can be foreseen.

The present document focuses on critical functions of some systems or sub-systems of the NeXOS scope. The ongoing design of NeXOS sensors allows to provide general views but not yet accurate support. It is planned to fully address reliability and robustness issues in task 3.4. But if we want to be efficient in this exercise, we need to share general views of functional analysis and illustrate with real cases.

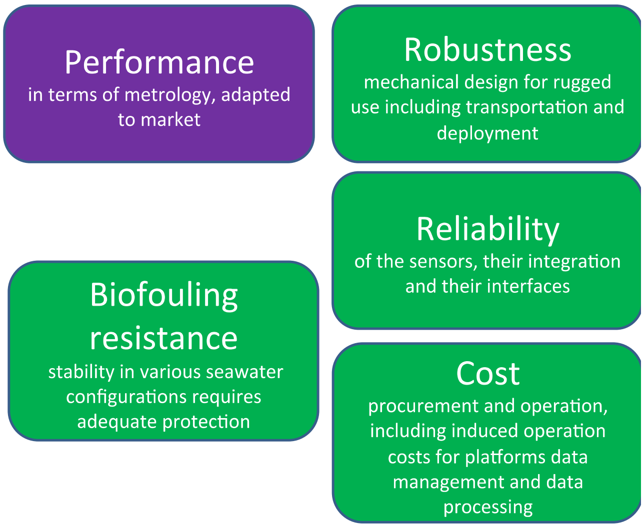

Figure 2 : Five major requirements for the sensor system development (from Description of Work). Biofouling resistance is addressed in Tasks 3.2 and 3.3, Reliability and Robustness in Task 3.4, Cost in Task 3.5.

From the first report dedicated to Technology Readiness Level (D3.1 [2]), it appears that the skill and methods of the NeXOS community show a clear awareness of the needs to develop and design using a step by step approach with regular validations and tests. The way to reach TRL 6-7 is well mastered in general. The few weak points we were able to detect are coming from:

- A lack of anticipation of the risks of the development (risk management plan)
- Some organizational and economic factors expressed rather late in the development process due to the priority given to technology and science. This can be seen in the questionnaire we used in D3.1 on topics such as anticipation of market needs, of manufacturing at larger scale, of security issues.

For this reason, this second report (D3.2) is targeted towards a support to risk analysis, taking into account organizational aspects. It is assumed that this will provide references for the more detailed studies on reliability to be performed in Task 3.4 but also to open a debate on some critical issues common to several NeXOS developments.

3 THE NEEDS OF RISK ASSESSMENT IN NEXOS CONTEXT

3.1 Needs of reliability analysis

Reliability analysis in the context of marine sensor systems is in many cases a key issue as well as an important driver of cost. Some sensors will be deployed for long term autonomous missions, some of them, for instance on-board Argo Floats, will never be recovered. It thus needs to be carefully performed despite the rather small amount of data on failure rates available. The top ("fear") events may occur during operations at sea but also during several steps of the equipment preparation and data dissemination process: metrology, associated metadata, processing, etc. In order to achieve this goal, it is necessary to consider several alternative configurations of the system design in such a way that functional specifications remain unchanged but enhance dependability. This is framed in the so-called reliability allocation problems [6], usually addressed by firstly obtaining Fault Tree models of the system and then performing cost-constrained optimization of whole system reliability. The most common criteria used to overcome reliability issues consist in applying redundancy on critical components to provide backup in case of failure of some component, use diversity (i.e. components from different manufacturers) in redundant parts so as to avoid common causes of failures and employ physical dispersion (i.e in a redundant configuration, locate components in different parts of the system).

In NeXOS, several phases are necessary in order to apply this analytical approach to the planned developments and use cases. NeXOS sensor developers were asked to provide input accordingly and we hereunder provide an overview of some of the expected cases, without going yet into details.

3.2 Key function of the anti-fouling device

The biofouling may invalidate sensor measurements within days to weeks when environmental conditions and sensor characteristics are prone to its development. This generally is the case for surface and near surface measurements or nutrient-rich oceanic areas. As maintenance is needed in order to bring sensors back to their nominal characteristics, fouling is a major cost driver for ocean observing systems.

For every sensor system, a particular innovative input for sensor **biofouling protection** will be evaluated in NeXOS and, if relevant, included.

The antifouling subsystem in a sensor system is mainly devoted to ensure reduced maintenance.

Anti-fouling subsystem

	Access, legal, environment or health issue	Equipment loss	Equipment malfunctioning	Data not collected or not usable	Maintenance	In NeXOS
Top event avoided or reliability enhancement		Barnacles, oysters,... in the sensing or actuating zones	Wrong measurement Sampling disturbance	Diminish the "out of range for fouling reason"	Time between maintenance From 2 months to 6 months or one year.	See next table (Table 2) Objective of Tasks 3.2 and 3.3
Induced top event or reliability loss	Only TBT poisoning case		wiper stuck in the sensing zone	Interference of chlorination with measured parameter		

Table 1 - Top events and reliability for anti-fouling subsystems.

The traditional situation is either to have a technical control and cleaning action very often (monthly on some sites) or that an expert is regularly looking at the results with remote tools and checks the validity of data. In the second case, the expert must launch a rapid intervention to go and clean the sensor. In many cases, the maintenance comes too late and an exchange of sensors is needed.

In this process, the action which will determine the success or not of the sensing sequence is the availability and skill/experience of an environmental data expert. This can be managed in high level oceanographic institute with skilled personnel dedicating time to quality checking of time series automatic acquisition in real time or performing by themselves short duration experiments such as cruises. It is a strong limitation to an extension of oceanographic measurement.

In addition, the experience shows that once a biofouling induced drift has been detected on one or more parameter, it is often too late to proceed to a recovery. The thickness of the biofilm is such that a complete manual cleaning is necessary and most of the time a new sensor calibration too.

Each of the sensor antifouling technical solution has its own limitation, objectives and mode of command. In order to better understand the importance of the NeXOS WP3 developments we can present these various techniques in a synthetic table (Table 2).

Type of fouling protection technology	Objective	Limitation	Other characteristics	Mode of command	NeXOS or most common application
Hydrophobic coating	Preventing	Not for slow water flux	Passive	Not sequenced	Trios
SnO_2 coating	Preventing		Whatever water flux, low energy consumption, active	Sequenced	Ifremer
Electrolytic chlorination	Preventing	Not for strong water flux	Active	Sequenced	Ifremer, nkei
Chlorine bottle (bleach)	Preventing	Large volumes necessary	Active	Sequenced	Ferry boxes, Ifremer coastal buoy network, …
UV light	Preventing	Energy consumption	Whatever water flux, Active	Sequenced	
Poison (TBT)	Preventing	Health issue	Passive	Not sequenced	ARGO floats
Copper screens	Preventing	Perturbation of measurement	Passive	Not sequenced	Several coastal sensors in the market
Wiper	Curing	Energy consumption	Active	Sequenced	Coastal sensors
Water-jet	Curing	Energy consumption	Active	Sequenced	Trios (To be confirmed)

Table 2 - Limitation, objectives and mode of command of main anti-fouling technologies for marine sensors.

One innovation planned in NeXOS is the anti fouling management system. The DoW says: “ As biofouling is the most important source of uncertainty, NeXOS will increase the reliability of sensor systems through an integrated antifouling management system “.The qualitative remarks of Table 2 apply differently according to the area of the ocean but we will try to keep provide general results.

The main objective in this field in NeXOS *“is to develop an innovative antifouling protection* *control systemfor the sensors. This cost-efficient, small size, system will increase reliability and reduce sensor maintenance cost. Up to now, specific types of sensors such as optical sensors have been protected against biofouling by a wiper, copper parts or copper shutters mounted on the sensor. These techniques are constraining the mechanical design and introduce a risk for in situ seawater instruments. The idea of the proposed technique is to get closer to the transducing interface, and specifically to implement active biofouling protection: a biofouling protection control system*

We propose to develop and test (then demonstrate on an integrated system in WP3.2) this protection method with a technique that builds upon prior developments validated at Ifremer 's laboratory. The technique will be implemented on the sensors developed in the project, and its performance validated at sea in WP3. In addition, this WP will solve a lack in the strategy used to protect sensors against biofouling. Many of the protection techniques require a source of energy, which is solicited independently of the biofouling state. So, in order to optimize the energy used to prevent biofouling to disrupt the measurement, the idea is to condition biofouling protection system via a new biofilm monitoring technique recently developed and validated by ISMAR-CNR (ALVIM biofilm monitoring sensor) as an integrated tool for optimization of the protection system." (Text of DoW [1].)

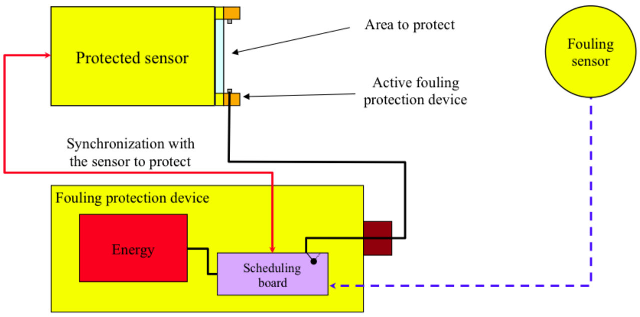

Figure 3 – Command scheme of the innovative antifouling protection control system for the sensors

The mention in Figure 3 of an active fouling protection device corresponds to the will to master the fouling protection and not undergo according to the variability of natural events.

The NeXOS fouling protection innovation provides keys to open major technological locks:

- Prepare the way to avoid the intervention of an expert in real time to check that biofouling protection is sufficient.
- Open the way to triggering from a fouling preventing mode to a curative one (same as the preventive with more intense action or additional curative technique such as wiper or waterjet).
- Open the way to redundancy or other improvement issued from system analysis.
- Optimize the energy consumption of fouling protection.

Final aim is to reach the maximum sensor operation duration without maintenance given a biological activity in a site. The site dependence may result in various thresholds to treat the fouling sensor input.

3.3 Case of a High maturity platform: ferry box.

Some optical sensors developed in NeXOS WP5 will be demonstrated on board Ferry boats, connected to the so called "Ferrybox" system (WP8 and 9).[1].

The decadal experience in these Ferrybox system has finally resulted in a mature technology and well organized operational oceanography component (http://www.ferrybox.org/). The reliability of NeXOS sensors have to be analyzed with a good understanding of the limits of the connection offered by a Ferrybox.

What can we plan to increase the availability of the NeXOS sensors connected to Ferrybox? Can we introduce redundancy?

Ferrybox

	Access, legal, environment or health issue	Equipment loss	Equipment malfunctioning	Data not collected or not usable	Maintenance	In NeXOS
Fault according to experience	The contracts between ship owner and scientific institute hardly detail the daily human relations: - Access onboard during harbor stop - Relations with marine transmission officer	Only case reported concerns the sale of the ship.	1st Communication 2nd external (ship) water circuit. e.g. biofouling after a long stop, corrosion stainless steel-copper. 3rd Internal circuit: pump and valves.	Due to communication cuts inside the ship or through the connection segment from ship to shore (GPRS and Satellite). Metrology of sensors must come be done on-time.	Remote maintenance available Filter changed every week Calibration every month Twice a year, full maintenance including change of pump or valve.	Integration and validation in WP8, demonstration in WP9.

Table 3 - Faults in Ferrybox systems.

Interfaces between a service provider and a user, is often critical ; this is more evident when the contribution of the ship owner is not part of his core business. On Ferryboxes, the Access onboard to the oceanographic equipment is sometimes difficult especially when the ferry does not come to the harbour everyday on regular schedule.

A better availability or a limitation in maintenance cost could result from improved fouling protection and from redundancy in data communication link and redundancy in pumps and valves.

But implementing the fouling protection of the pipes of the ship is difficult to negotiate with the volunteer ship owner.

The data link devoted to the security of the ship is redundant, but it is not the case for the transmission offered to the Ferrybox. Most transmission losses or long delays are due to the dependence on the ship links. The only true redundancy would then rely on an independent direct link such as a satellite link (data transmission is presented in a different case in § 6.

Redundancy of pumps and/or valves may be further investigated once the maintenance frequency for metrology reasons is decreased.

We may conclude that the maintenance frequency of NeXOS sensors will be a key issue also for Ferryboxes installations with a specific and well known platform context.

These remarks may be extended to sensor systems on board other ships of opportunity and even Research Vessels.

3.4 A case which benefits from ARGO floats experience: ARVOR CM

Profiling floats are covering the Ocean for the sake of the ARGO international program (http://www.argo.net/). With more than 3000 profiling floats providing a weekly CTD profile from 2000 mwd to the surface, it is the backbone in-situ technology of operational oceanography.

The development of these lagrangian (following water masses) instruments was initiate by acoustic drifters (MOVE experiment, SOFAR floats, WOCE Program, Marvor). The difficulty to address the reliability for these 4 year life instruments comes from the fact that only a very small number is recovered on beaches or by ships. It is then very difficult to understand the malfunctioning and reasons of loss. For each design modification or qualification of new components, the designers have to follow the technical parameters remotely for a significant number of prototypes cycling in the ocean. When malfunctioning and abnormal losses occur, it is quite common to simulate the behaviour in pressure tank, testing pool,.. with strictly similar prototypes.

Initially measuring Conductivity Temperature and Depth, the ARGO floats are incorporating now dissolved oxygen sensors. Some prototypes demonstrated the interest to add more sensors. H2020 projects are under evaluation to generalize the implementation of these additional sensors.

But the process of ARGO float qualification and ARGO float sensor qualification are too long at NeXOS scale. If we take the example of oxygen sensors, each step for an additional TRL level means 3 years due to long tests at sea: TRL6 to TRL 7 EURO-ARGO Preparatory Phase, TRL7 to TRL 8 NAOS French national project, TRL8 to TRL 9 Atlantos (H2020 project under evaluation). It is planned to use profiling floats for demonstration in WP9. For the sake of the WP3 and 4 tasks at least, Ifremer proposed to use the coastal multi-parameter version ARVOR CM to be able to interact with sensor/float interface design if needed.

Multisensor profiling float

	Access, legal, environment or health issue	Equipment loss	Equipment malfunctioning	Data not collected or not usable	Maintenance	In NeXOS
Fault according to experience	Not a problem yet. Lithium batteries questioned in some countries.	Very common. In coastal zone, fishing activity is the dominating reason.	1st- Software in early stage of each new profiler. 2nd- In the long range, hydraulic components or pistons (depending on the manufacturer) 3rd- Satellite transmission through a unique antenna. The diving duration may be disturbed when a profiler (especially coastal) has been waiting on soft seafloor sediment for some time.	Several "illnesses where encountered such as drift of pressure sensors (the same provider for all manufacturers!). Validation of calibration process is long for new sensors. This can only be done thanks to comparison with models of data acquired by a large number of profilers.	No maintenance for the ARGO floats. For the coastal version, refurbishing seems possible provided an improved robustness.	Integration and validation in WP8, demonstration in WP9. Use case in parallel to gliders.

Table 4 - Faults in Multisensor profiling float

Reliability assessment are regularly performed on ARGO floats by each designer from technical parameter database. The actual faulty component is not known in many cases due to the fact that the profiling floats cannot be expertised. The assessments are consequently based on assumptions and probably give a too large importance to the few "illnesses" that have been proved in the past.

An independent analysis was done by Kobayashi 2009 [7]. It is reported by Brito [10] to compare with gliders.

First generation operational profiling floats had a life expectancy of 4 years, performing 150 cycles during this period. However in 2001 only 20% of the APEX floats could meet this requirement. The fact that faulty floats could not be recovered made it difficult to identify the root causes for failures. Nevertheless, research institutes and the manufacturer engaged in fault investigations and a number of improvements were made as a result. For example, the batteries of the early floats had a design vulnerability that meant that every time a battery cell was damaged it caused a chain reaction, in which other battery cells in the same pack would also fail. The battery circuit design was changed; a diode was introduced between cells so that if one cell is damaged it will not damage the cell next to it.

The pump used in the early APEX float (US design) allowed small sediments to mix with the oil. On PROVOR (French design), the flow in the high pressure valve was modified by long term degradation of oil on the seat of the valve.

The cost of ARGO floats is dominated by the sensor system cost (from SEABIRD Electronics). This does not push to design with redundancy of components. Nevertheless, in some special geographical zones, double satellite transmission has been envisaged (Iridium+ARGOS). Preliminary tests showed no gain is reliability and more complexity in software, it was not implemented.

The system redundancy is obtained by an addition of ARGO profilers in areas where more losses are experienced. This failed as a redundancy in 2009 when an error was detected on **all** the ARGO profilers (whatever design and manufacturer) due to malfunctioning of pressure sensors provided through SEABIRD to all the manufacturers during a few years.

In a more open context of the multisensor profiling float in coastal areas, the time between calibration of the sensors will be crucial. It must ideally equal the duration of the power of the batteries. Sensor protection, or strategies of use of multiple sensors of the same type may be envisaged in NeXOS. In any case, the calibration frequency will have to be low for a sensor to be candidate to profiling float integration.

The satellite transmission is common with the gliders and addressed in §6

3.5 A complex platform, well analyzed: the glider

Gliders are important in Nexos as potential platforms for several new sensors. It is planned to demonstrate NeXOS achievements on gliders in WP9.

Thanks to the GROOM project, Brito et al. [8,10] were able to analyze a reasonable number of operations of gliders from all European operators.

The glider operational data consisted of 205 missions collected over a period of two years by the GROOOM project consortium. To avoid the potential for biases, the aim was to collect operational data from glider user consortium only [10]. Furthermore whether or not a failure leads to loss of the vehicle is very much dependent upon the available options for recovery.

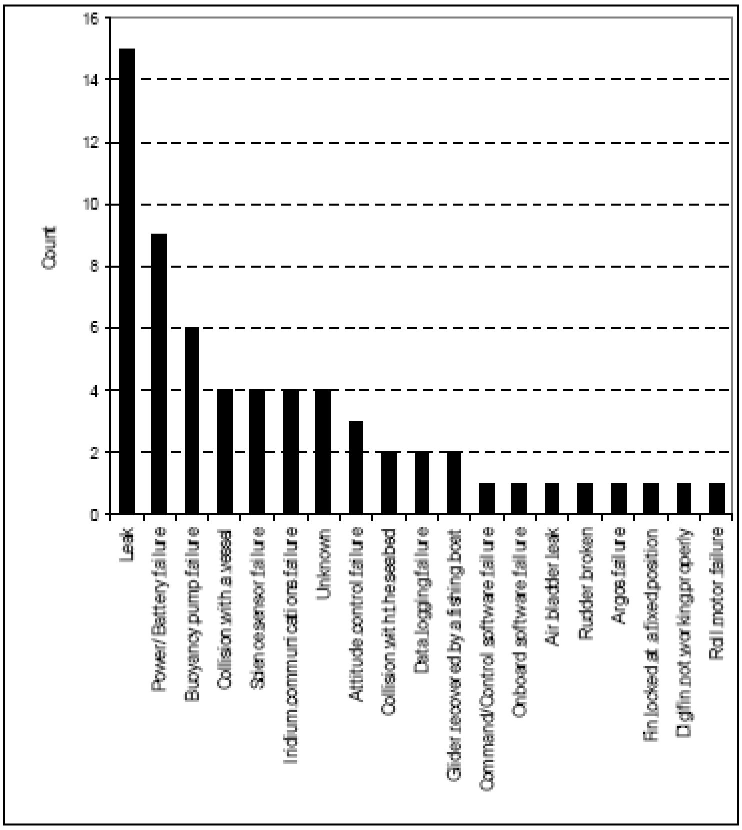

Figure 3 – Failure mode for the group of undersea gliders studied in GROOM (FP7 Design Study)

Failure due to a leak was the most observed failure mode. Fourteen out of fifteen of these failures occurred on Slocum vehicles The second most common failure mode was power/battery issues, these occurred seven times more frequently for Seagliders than for Slocums (two designs of gliders). Without further information GROOM experts cannot give an explanation for this difference. The third most common failure mode was buoyancy pump failure. The collision with seafloor due to misleading indication of sensor is not a primary fault to be kept as there is no correlation between the status of the altimeter and the probability of the glider being lost.

The conclusion of Brito et al. [8] is expressed in term of redundancy of vehicles (gliders). They show that for deep undersea gliders the GROOM community would need to deploy 10 gliders in order to achieve 0.95 probability of success fully providing continuous coverage for 180 days without replacement. A fleet of 20 gliders would be required to have a probability of 0.92 for continuous coverage over 360 days. For shallow gliders GROOM team concluded that the probability of not aborting a 30 day mission is approximately 0.5. For deep undersea gliders the probability of not aborting a 90 day mission is approximately 0.5.

Glider

	Access, legal, environment or health issue	Equipment loss	Equipment malfunctioning	Data not collected or not usable	Maintenance	In NeXOS
Faults according to experience	Legal aspects are not yet an issue. Use of Lithium batteries limited in some countries	Quite common See text above.	Studied by GROOM project [8], [9]	Transmission losses are the more common lack of data. Calibration of sensors (except CTD) difficult to follow up	Time between return to glider port: From 1 week to 4-5 months	Integration and validation in WP8, demonstration in WP9. Use case.

Table 5 - Faults in glider system

For the existing Gliders there is clearly not enough experience of actual reliability performance, so it is necessary to use generic data with corrections based normally in engineering judgement. This is a very mature end well known field among RAMS (Reliability, Availability, Maintainability and Safety) engineers which requires of available data bases, engineering experience and to follow some synthesis steps. A general explanation and data bases for offshore technologies can be found in the literature [14,15].

Essentially the procedure start using assumptions and engineering judgement to select for each component of a Glider a base failure rate λ_b, the following is to decide the failure modes to consider for each component and its failure proportion $p(F)$, the next is to adopt the stress factor values related to the environment $S_1$and component nominal rating S_2. Finally the corrected failure rate λ_c can be computed using the following equation:

$$\lambda_c = \lambda_b S_1 S_2 p(F)$$

As an example a basic series Reliability Block Diagram (RBD) for the Slocum glider has been developed (Fig. 4), the components/elements considered were: Antenna, Inflatable Bladder, Science Bay, Battery pack, Buoyancy pump, Altimeter and Seals. For each of them a synthesized failure rate was obtained using the abovementioned references and the assumption of exponential law was made for the reliability of all the components (Table 6).

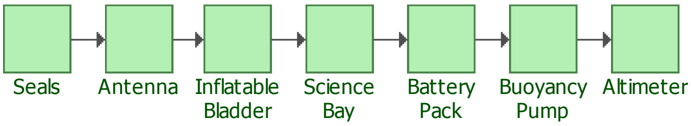

Figure 4.- Slocum Reliability Block Diagram

Block Failure Distribution Legend

Battery Pack: Exponential μ=100000; γ=0

Buoyancy Pump: Exponential μ=4350; γ=0

Altimeter: Exponential μ=28600; γ=0

Inflatable Bladder: Exponential μ=1000000; γ=0

Antenna: Exponential μ=55600; γ=0

Seals: Exponential μ=250000; γ=0

Science Bay: Exponential μ=5810; γ=0

Table 6 - Components, Reliability law and inverse of the failure rate for the Slocum glider RBD

The diagram was processed with the software Blocksym [16] and the System Reliability equation was:

$$\text{Slocum\_Reliability}=\left(R_{\text{Seals}}\cdot R_{\text{Antenna}}\cdot R_{\text{Inflatable Bladder}}\cdot R_{\text{Science Bay}}\cdot R_{\text{Battery Pack}}\cdot R_{\text{Bouyancy Pump}}\cdot R_{\text{Altimeter}}\right)$$

The solution of such equation is the Reliability vs Time curve represented in the Fig. 5. In the same figure the experimental results of the GROOM project have been included. As can be seen the computed reliability is near form the observed for the 90 days mission in GROOM and serve as a preliminary validation of the methodology, of course is expected that further refinements of the synthesis process can produce more accurate results.

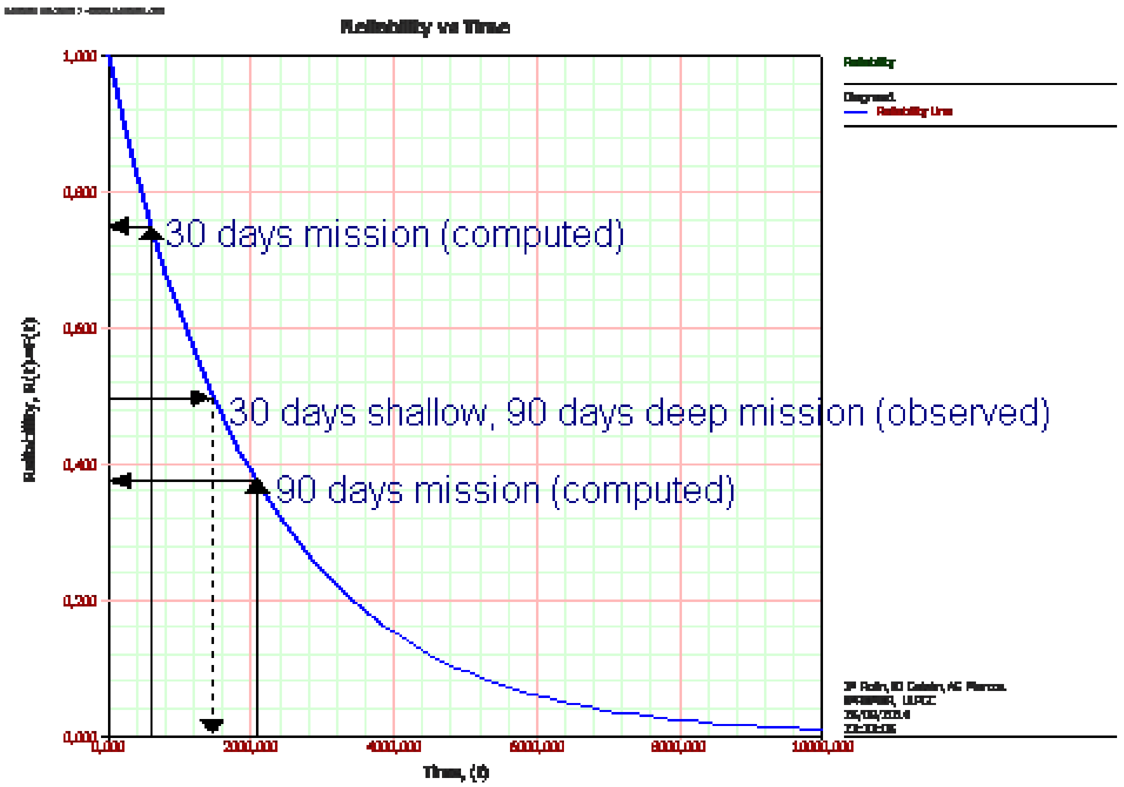

Figure 5 – Slocum Reliability vs Tme plot.

The same methodology can be used to refine de Reliability Block Diagrams considering redundancy (eg. more component in parallel) and diversity (components redundant form different providers) in order to increase the gliders expected reliability. The physical dispersion of the redundant components/elements/links inside the glider can contribute to increase the reliability reducing the associated common cause failures. The RBD can include Maintenance characteristics and the whole design optimization process can be performed by a computer [6] using single/multi-objective evolutionary algorithms. The glider models can be performed using Fault Trees (FT) instead of RBD, being the main difference that RBD are more oriented to analyze the system as a whole and the FT are more oriented to specific undesired events, but both methodologies can be used and can produce similar results.

3.6 Sensor connection to fixed point observatories: the Junction Box

As described in the EMSO and ESONET projects, fixed point observatories are either cabled to land or stand alone communicating through acoustics in water and satellite hertzian transmission outside. In both cases, the interface from the sensor sor sensor systems is made through a Junction Box providing power and collecting data. Such observatories are mentionned for the demonstration of NeXOS.

A rough system analysis is easily done in eulerian observatories at design stage but data on some componants is still scarce [11]. The underwater cable part benefits from the experience of the subsea telecom industry. The faults on node, junction box and sensor systems are not reported systematically. It has been envisaged to promote an international cooperation on this topic between Japan, Canada and Europe.

Junction Box

	Access, legal, environment or health issue	Equipment loss	Equipment malfunctioning	Data not collected or not usable	Maintenance	In NeXOS
Faults from experience	Cabled observatories require to follow national procedures for landing sites. Limitations due to fishery or Marine Protected Areas.	This occurs in busy areas where navigation rules are not followed (Case of Marmara Sea). Geohazard monitoring is also risky.	1st- Electrical power default 2nd – O-rings and leaks 3rd – subsea connectors including their manipulation by ROV. 4th – Material ageing or unreliable buoyancy	Unreliable sensors. Calibration for a long period shows difficulties to interpret drifts. Fouling protection difficult for long periods. Quality check late with respect to real time data acquisition.	Yearly maintenance time (to increase). Remote maintenance, remote re-configuration	Integration and validation in WP8, demonstration in WP9. Most general application for WP4 interface issues.

Table 7 - Faults in Junction Box of subsea observatories

For the subsea observatory platforms in general and Junction Boxes in particular, improvements can be expected with detailed reliability analysis.

Redundancy is proposed in cabled observatories. Neptune Canada decided to have a loop shape with two cable landings. Alcatel design of Neptune Canada and ESONIM Project (Reference documents accessible under request) presents several redundancies along the power and fiber optic networks. ESONET published recommendations (ESONET Label [12]) for acoustic and satellite communications to be redundant (two acoustic modems, two satellite modems).

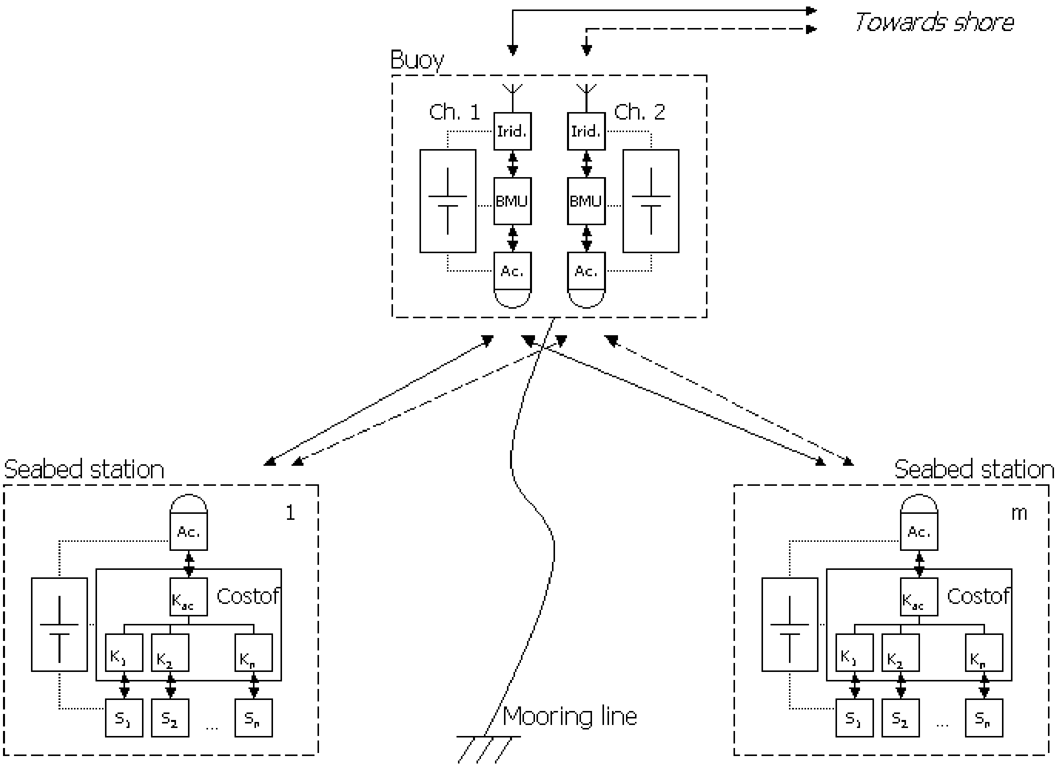

Figure 6: Functional sketch of a non cabled observing system showing the communication redundancy. Sensors are addressed as S_i; K_i figure electronic interface boards; Ac_k are acoustic modems; BMU means Buoy Modem Units; Irid is Iridium satellite modem.

NeXOS should examine the opportunity of redundant sensors and safer electronic interfaces. The work carried out in WP4 (Deliverable D4.3 [13]) on smart sensors opens the way to analyze all the aspects of sensor to observatory link such as re-usability, interoperability, software open source.

3.7 High data rate case: Passive acoustics

Passive acoustic sensor systems are quite robust and may be deployed during decades (see CTBTO, military submarines,…).

The quality of the electronics and the software design validation must be well established.

Passive acoustic sensor system

	Access, legal, environment or health issue	Equipment loss	Equipment malfunctioning	Data not collected or not usable	Maintenance	In NeXOS
Faults according to experience	On cabled observatories or long time moorings, the acceptance by military authorities may be a limitation.	Reliability of moorings. Leaks.	Damaged transducers (ceramics). Connectors Electronics Noise interferences (electronic, mechanical, modems)	Calibration not well performed, Electronic noise Software too complex Electronic interface	Several years. Fouling and ageing of thermoplastic or rubber of transducers	Content of WP6. Integration and validation in WP8, demonstration in WP9. Use case.

Table 8 - Faults in passive acoustic sensor

Redundancy is quite common: two made of transducers for instance.

3.8 Optical sensor using flow analysis: carbon sensor

From the experience of earlier flow analysis automated sensors for in-situ use, we can suggest some tracks to be applied more precisely to the case of the new carbon sensor.

Carbon sensor – flow analysis

	Access, legal, environment or health issue	Equipment loss	Equipment malfunctioning	Data not collected or not usable	Maintenance	In NeXOS
Faults according to experience	Used reagents are still present after the analysis. Storing this liquid is the usual method.	.none	Fluidics, pumps, valves, tubing leaks. Optical measurement cells and circuit are usually robust. Time life of lights.	Variation of optical conditions (lights). Changes /ageing of reagents. Cycles not complete (electronics)	Depending on reagent life-time. 1 year maximum.	In WP5 Integration and validation in WP8, demonstration in WP9.

Table 9 - Faults in flow analysis carbon sensor

Redundancy may be envisaged in lights, valves and pumps.

Self calibration with pure water or reference solution is quite easy and is widely used. It may compensate months of ageing of the optical components and the reagents.

3.9 Reference for integration: multi-parameter probe.

All kind of multi sensorprobes can be found on the market, from reference CTDs used to valídate models and processes in physical oceangraphy to simplified probes such as Recopesca.

Multi parameter probe

	Access, legal, environment or health issue	Equipment loss	Equipment malfunctioning	Data not collected or not usable	Maintenance	In NeXOS
Faults according to experience		Extended corrosion or shocks on sensor heads. Leaks.	Interface problems, leaks,connectors, Electromagnetic compatibility	Software: compatibility, Internal formulae misunderstood in drivers. Fouling Interference between individual sensors.	Calibrated separately or calibration of the whole probe? From 1 week to 4-5 months	Reference for WP3. WP7 EAF sensor system is a low cost version.

Table 10 - Faults in multiparameter probe

4 GENERAL FUNCTIONS

For the NeXOS products, main functions are similar:

- To measure in-situ physical parameters in the ocean with rugged probes (*with protected probes for Ferrybox case*)
- To measure technical parameters associated with the scientific instrument
- To provide the metadata (position, reference time, sensor type, quality flag,…)
- To transmit the data to data center
- To transmit the data to the ocean environment operational system when near real time transmission is available
- To allow the networking of data collection at European level

- To allow remote maintenance (remote calibration if feasible)

The developments in NeXOS might bring more complete functions with: smart sensor interface and computing capacities (WP4), fouling protection capacities (WP3).

5 INTERFACES

To perform a good system analysis, the interfaces must be well defined. We recommend for each NeXOS component to examine the conditions of use and look for the other systems or sub-systems related at a time of another of the Life Cycle.

This exercise has been done for EAF sensors [3].

More generally, the following questions have to be replied to:

- What are the communication infrastructure used along the data transfer process? It includes commercial telecom providers, internal segments of internet with firewalls,…
- What are the interfaces with the platform of the sensor, and with the various infrastructures used to transport, bring to the sea, deploy, recover, …? This includes local PC onshore or onboard a vessel, power supplies used occasionally,…
- What are the equipments mechanically in contact with the NeXOS system in operating conditions, in testing conditions, in transport conditions?

6 Analysis of the communication segment

We saw above the importance of communication segment for all the platforms used by NeXOS. It is in some cases the dominating failure of the existing systems. WP4 is proposing innovation along this segment such as the sensor to platform interface.

We can illustrate one of the cases, the glider communication, thanks to an analysis presented by GROOM ([8], [9], [10]).

The communication system failures of a glider include:

• Inappropriate user commands or combinations of commands.
•Software errors in the vehicle or in the communications modems.
•Component failure in the vehicle modems or their interconnecting cables.
•Physical damage to the antennas or water ingress into the antennas.
•Problems somewhere along the chain between vehicle and user when using satellite communications
•Problems at the user location with antennas, modems, software and user understanding

The exhaustive reasons were analyzed by Gliders Research for Ocean Observation and Management (GROOM) when collecting glider operational data from year 2008 to 2010 [8]. The data collected as part of this project was used to support the arguments captured in the probability tree they had established. A total of 205 underwater glider missions were recorded during this period. During the period of this study ten gliders were lost: three Slocums and seven Seaglider1000s. The uses for Slocum losses are unknown. The Seaglider1000 losses are suspected to have been caused by:

- **Iridium communication failure (**three gliders): iRobot'sSG546(TFP), NOC/PLOCAN's SG531 (Altair) and AlfredWegenerInstitut für Polarund Meeresforschung's (AWI)MK501.
- Power/battery failure (two gliders): AWI's MK 57 and MK 544
- Command and control failure (one glider) SG522 (UEA) .
- Collision with a vessel (one glider), G507 'Narwhal'(UEA).

Pilot error - events can result from piloting error:

•An unintended result from a combination of parameters provided to the piloting software. Some autonomous vehicles use mission script checkers to verify that the combination of parameters will not put the vehicle in an unsafe situation. Other manufacturers give more freedom to the user to set parameters .

•Incorrect choice of parameters.

•Formatting error by the pilot, where the vehicle does not then read the intended parameter value

The presentation of every suspected failure reasons , including the probabilities for the communication segment as well as other probabilities is shown in figure 5.

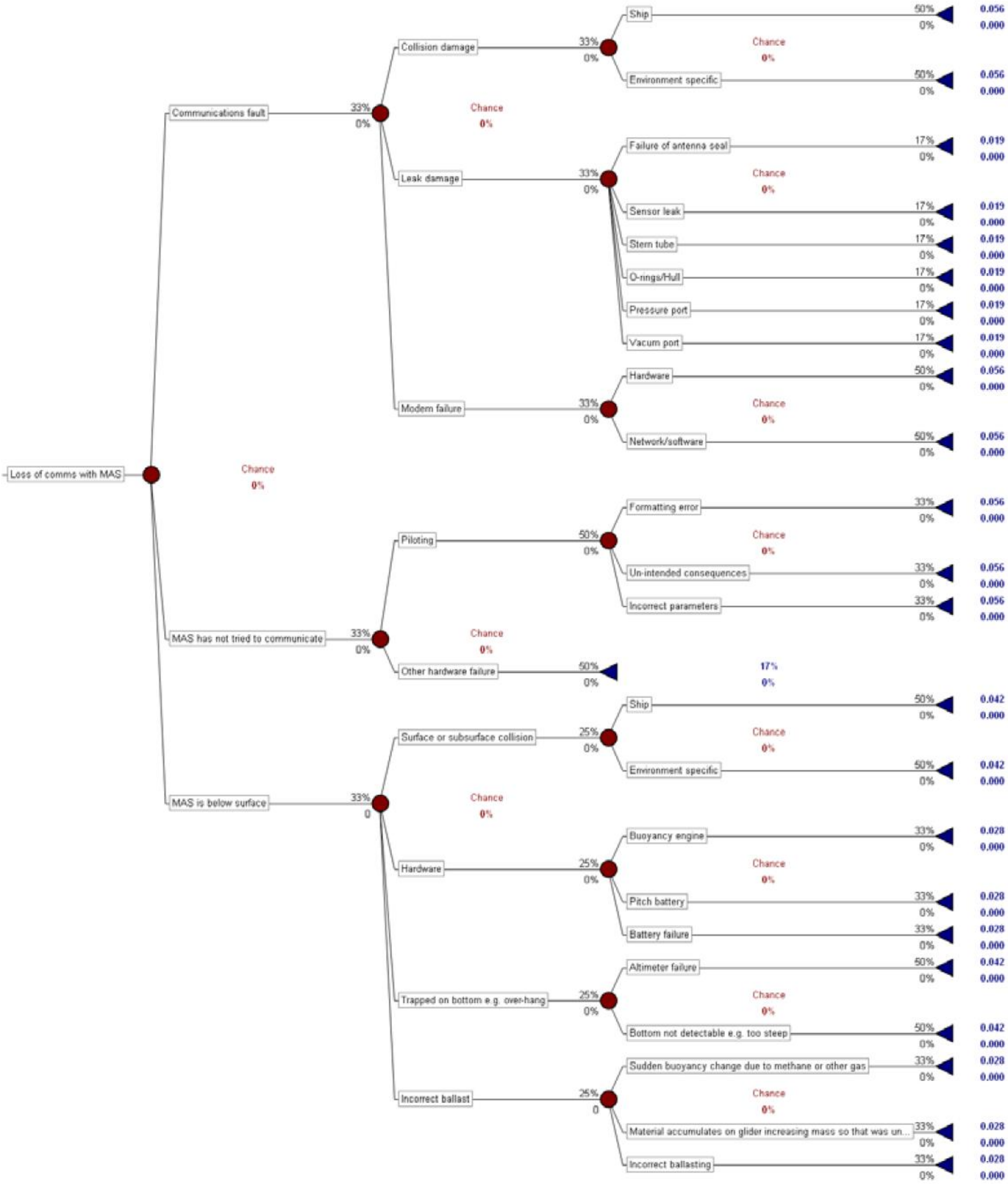

Figure 5 - Diagram presenting probability of failures for a glider (source GROOM) note the communication segment high figures.

When introducing new sensors on board glider, NeXOS teams should be prepared to provide data for such fault tree analysis.

7 CONSTRAINTS in OPERATING CONDITIONS

Another chapter of the functional analysis is the review of the constraints.

7.1 ENVIRONMENT CONSTRAINTS

They result from the life cycle (§8) but for oceanographic instruments, most of the marine environment constraints are covered by classes of external conditions and result in standard test files [4].

7.2 MODULARITY, INTEROPERABILITY

All probes must work with any platform. Modularity and interoperability are ensured by hardware and software interfaces. Mechanical interface must be robust and bring no significant additional source of failure.

7.3 MAINTENANCE CONDITIONS

The maintenance period is a major criterion for NeXOS. The level of skill and tolls required must also be addressed.

7.4 CORROSION

The NeXOS sensors must withstand n years marine operation without corrosion.

For fisheries sensors, profiling floats, n = 5

For standard scientific systems, n= 10

For subsea observatories, offshore oil and gas, n= 25

Recommendations are made in [12]

7.5 HUMAN SECURITY

Compliance with Health and Safety regulations is mandatory. The TRL 6 level is not reached without the establishment of a plan for security.

TRL 7 requires a Health and Safety documentation for the users.

We can recommend a Human security approach based on :

- no end user intervention on system (automatic operation). The installation or maintenance is done by a trained technician.
- low risk electrical strategy. All components are low voltage to avoid electrical risk.

7.6 ENVIRONMENT PROTECTION

Thermoplastics may be used in limited quantities. Induction of litter on the sea floor must be limited to the cases of loss of equipment. Ballasts left on the seafloor must be limited and replaced by other systems when possible.

8 LIFE CYCLE AND OPERATIONAL PROCESS

A detailed exercise of life cycle description has been presented in the first deliverable of Task 7.1 “Functional Specification Report of the Ecosystemic Approach to Fisheries” (D7.1 [3]). Such analysis is needed for the major developments of NeXOS in order to evaluate robustness constraints and determine the corresponding testing plan [4].

As an example:

- Determination of the deployment plan
- Choice of the ship and organization of data management
- Preparation of equipment
- Storage and shipment

The material can be stored by the manufacturers, retailers, shipowners, on board or research institutes. The material can be shiped by road, train or plane.

- Installation on board the ship or the platform.
- Data flow, management and processing
- Data synthesis delivered to stakeholders
- Recovery, shipment back
- Storage before next deployment.

9 Conclusions

The systemic approach of NeXOS comes in the oceanographic field where this practice is not so well documented. The quality of the methodology and establishment of objectives in WP1 [17,18] brings a common understanding to the NeXOS consortium. Thanks to the review of platform and sensor system reliability performed in this report, we have a basis to position the innovations of the project with respect to the various types of oceanographic systems. The experience of Universidad de las Palmas de Gran Canaria [6] brings the tool box to enhance dependability without changing the functional specifications. The TRL estimates will be continued in parallel to measure improvements, leading to update [2].

The robustness, reliability and cost issues will be addressed as next steps of WP3 using this basis.

10 Reference documents

[1] FP7-OCEAN-2013.2 Nexos project DOW. Next generation, Cost-effective, Compact, Multifunctional Web Enabled Ocean Sensor Systems Empowering Marine, Maritime and Fisheries Management.Grant agreement no: 614102. 2013.

[2] NeXOS Deliverable D3.1 - J.-F. Rolin et al. «Technology Readiness Level Report" 140415-NXS-WP3_D.3.1-v.final -

[3] NeXOS Deliverable D7.1 – P.Woerther et al. "Functional Specification Report of the EAF" - 27052014-NXS-WP7_D.7_1-v_4_final

[4] Standard AFNOR NF X 10-812 Marine environment – Oceanographic instrumentation – Guide for environmental tests.

[5] Standard EN 1325-1:1997- Value management, value analysis, functional analysis vocabulary Value analysis and functional analysis Published : January 1997

[6] B. Galván, G. Winter, D. Greiner, D. Salazar, and M. Méndez, "New Evolutionary Methodologies for Integrated Safety System Design and Maintenance Optimization," in Computational Intelligence in Reliability Engineering SE - 5, vol. 39, G. Levitin, Ed. Springer Berlin Heidelberg, 2007, pp. 151–190.

[7] Kobayashi, T., B. King, and N. Shikama, 2009: An estimation of the average lifetime of the latest model of APEX floats. J. Oceanogr., 65, 81-89.

[8] Brito, M.P.; Smeed, D.A.; Griffiths, G.. 2014 Underwater glider reliability and implications for survey design. Journal of Atmospheric and Oceanic Technology.

[9] Brito, M.P.; Smeed, D.A.; Griffiths, G.. 2014 Analysis of causation of loss of communication with marine autonomous systems: a probability tree approach. Methods in Oceanography.

[10] Brito, M.P.; Smeed, D.A.; Griffiths, G.. 2013, Undersea glider reliability and implications for survey design- Submission paper. NOC website.

[11] Auffret, Y., Rolin, J.F., Deliverable 8.2 Reliability of examined sub-sea infrastructures - 2012 - EMSO Preparatory Phase.

[12] Rolin Jean-Francois, Bompais Xavier (2011). ESONET label definition. http://archimer.ifremer.fr/doc/00061/17240/

[13] NeXOS Deliverable D4.3 – Del Rio et al. “High Level specification of architecture and components »

[14] Andrews and Moss, 1993.- J.D Andrews and T.R. Moss. Reliability and Risk Assessment. Longman Scientific & Technical. 1993. ISBN 0-582-09615-4

[15] OREDA Project, 2009.- Offshore Reliability Data Handbook. Prepared by SINTEF and distributed by Det Norske Veritas (DNV). ISBN 978-82-14-04830-8-.

[16] Reliasoft, 2014. http://www.reliasoft.com/

[17] NeXOS Deliverable 1.3 – Waldmann C. et al. Project Implementation Plan (PIP) from concept to development, integration, validation and demonstration

[18] NeXOS Deliverable 1.1 – Waldmann C. et al. Requirements Framework