D2.1 Operation analysis method

Work Package 2: Autonomous operations design: Requirements, design methodology, verification and validation
This document contains the methodology used to determine the main features of an operation.
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1. Introduction

1.1. Background

Autonomous mobile systems are systems capable of reasoning about and solving unstructured problems without the direct control of humans and are central to future exploitation of the ocean space. One goal of the SWARMs project is to provide a methodology that gives a structured way of analysing mobile autonomous maritime operations and systems. The goal of the methodology is to make the systems developers able to

\[ \text{design, develop and validate autonomous functionality efficiently} \]

by giving guidelines, principles, best practices and tools.

This methodology emphasizes that autonomy is not all-or-nothing. It is therefore created as a family of approaches that leads to a system with some degree of autonomy. Finding the correct degree of autonomy is of high importance, as this way of thinking leads to designs that are focused on solving the operation in an optimal manner (goal driven) rather than being technology driven.

A revised methodology based on SWARMs experience will be delivered as D2.2.

1.2. Planned workflow for SWARMs

This document describes a methodology for analysing autonomous sub-sea operations. Since the planning of the demonstrator operations in WP8 and the middleware design WP3, is done in parallel with WP2, it is not possible to fully utilize the methodology in those WPs. Some methods have already been communicated to WP8, however, such as the AJA-tables (see Section 4) and the requirement format (see Annex B). The plan for this process is:

- WP2 communicates methods to WP8 to help start the work.
- WP8 uses the methods together with any other methods they need to plan the operation.
- D2.1 is delivered describing the first draft of the full methodology.
- WP8 uses D2.1 and D2.2 to further refine the operation design.
- WP2 uses the feedback and experience from WP8 and Task 2.6 to refine the methodology for D2.2.

A similar workflow will be used for the other viewpoints in the SWARMs Task 2.3 and Task 2.4.
### 1.3. Nomenclature

This section contains nomenclature for the SWARMs project.

**Table 1: Nomenclature**

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Agent</td>
<td>The word agent denotes a cyber-physical entity performing some or whole of the physical part of the operation.</td>
</tr>
<tr>
<td>Method</td>
<td>The word method is used as a structured way (e.g. sequence of steps, collection of questions) of acquiring certain knowledge. This knowledge should help in designing the autonomous operation or system in a better way.</td>
</tr>
<tr>
<td>Methodology</td>
<td>A methodology is a systematic set of tools, methods, principles, rules, and analyses for regulating a given discipline. Here the word methodology is used as the analysis of the methods, tools, etc. applied to designing autonomy for marine systems. The methodology offers a way to understand which methods, techniques or best practices can be applied to specific cases in order to achieve the best results.</td>
</tr>
<tr>
<td>Operation</td>
<td>The operation is the mission, job, task or procedure intended to be performed by the system, and has a main goal associated with it.</td>
</tr>
<tr>
<td>Operational safe state</td>
<td>A state or mode of operation an agent or system can enter in the case of an unwanted/unexpected event that cannot be handled in a determined way. This state or mode is one where the chance of harming itself or its environment is as small as reasonably possible.</td>
</tr>
<tr>
<td>Sub-operation</td>
<td>An operation can be subdivided into smaller parts, e.g. procedurally, in parallel, or conditionally. These smaller parts are named sub-operations.</td>
</tr>
<tr>
<td>System</td>
<td>The system is the human-machine solution proposed to solve the operation.</td>
</tr>
<tr>
<td>Task</td>
<td>A definite piece of work that has been assigned, or expected to be completed.</td>
</tr>
<tr>
<td>Reliability</td>
<td>Reliability or dependability refers to the ability of a system to function nominally. This relates to the probability of downtime due to repairs, accidents, or maintenance.</td>
</tr>
<tr>
<td>Safety</td>
<td>Safety is concerned with failures which affect life and nature.</td>
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## 1.4. Acronyms and abbreviations

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
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<tbody>
<tr>
<td>ACWA</td>
<td>Applied cognitive work analysis</td>
</tr>
<tr>
<td>AIRM</td>
<td>Aggregated Indices Randomization Method</td>
</tr>
<tr>
<td>AUV</td>
<td>Autonomous Underwater Vehicle</td>
</tr>
<tr>
<td>CUA</td>
<td>Cost-Utility-Analysis</td>
</tr>
<tr>
<td>HAZID</td>
<td>Hazard Identification</td>
</tr>
<tr>
<td>HAZOP</td>
<td>Hazard Operability Analysis</td>
</tr>
<tr>
<td>HTA</td>
<td>Hierarchical task analysis</td>
</tr>
<tr>
<td>JSA</td>
<td>Job Safety Analysis</td>
</tr>
<tr>
<td>LCC</td>
<td>Life Cycle Costing</td>
</tr>
<tr>
<td>LoA</td>
<td>Level of Autonomy</td>
</tr>
<tr>
<td>PAPRIKA</td>
<td>Potentially all pairwise rankings of all possible alternatives</td>
</tr>
<tr>
<td>PROMETHEE</td>
<td>Preference Ranking Organization METHod for Enrichment of Evaluations</td>
</tr>
<tr>
<td>ROI</td>
<td>Return On Investment</td>
</tr>
<tr>
<td>ROV</td>
<td>Remotely Operated Vehicle</td>
</tr>
<tr>
<td>TCO</td>
<td>Total Cost of Ownership</td>
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<tr>
<td>USV</td>
<td>Unmanned Surface Vehicle</td>
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</table>
2. Methodology description

The methodology is initially based on the SEATONOMY methodology [1]. It analyses an autonomous operation from three viewpoints that will be handled in different WP2 Tasks. An introduction to the viewpoints and their relationship is given below.

1. The operational viewpoint (SWARMs Task 2.1)
   This viewpoint concerns the overall design and specification of the operation. This means analysing the operation(s) the system is intended to execute, without considering the physical system in detail. The reasoning behind this viewpoint is both to facilitate a common understanding between system designers and end-users, as well as making sure that the system design will be grounded by the actual operation it is intended to solve. This will be developed in Task 2.1 and is the emphasis of this deliverable as well as D2.2.

2. The system viewpoint (SWARMs Task 2.3)
   The system viewpoint concerns the realization and composition of autonomous functionality in the physical system. This viewpoint is more concerned with the needs and requirements on how to create a working autonomous system. Requirements in terms of hardware and software are taken into account in order to accomplish the system's design and implementation. Within this viewpoint, details of the agent and system itself will be analysed. This will be developed in Task 2.3.

3. Verification and validation (SWARMs Task 2.4)
   The verification and validation viewpoint is concerned with how to make sure both system and operation behaves according to requirements (verification) and according to reason (validation). Validation by smart testing and operational scenarios is emphasized as a way to counteract the challenges of analysing infinite states and responses. This will be developed in Task 2.4.

The three categories or viewpoints must all be covered in order to make a design in accordance with the methodology. The way to use the methodology is an iterative and incremental approach, and is illustrated in Figure 1.
Figure 1: The methodology as an iterative and incremental process.

Work starts using the operational viewpoint, which aims to give a common understanding with other stakeholders regarding the operation that is to be performed.

Answering all questions and covering all angles is usually not feasible during the first iteration in operational viewpoint, since information on the actual physical system is lacking.

Finishing the operational viewpoint, one proceeds in the system (design) viewpoint which details the physical system, including sensors and communication.

With the end of that, verification and validation (V&V) should be undertaken. It is important to note that details in the system viewpoint may lead to the redesign of parts of the operational viewpoint. This is encouraged, and the work flow is carried through V&V to make sure that operation viewpoint is verified and validated in accordance with the new available information. Through V&V, it can be ensured that

- Hardware and software components undergo unit and integration testing.
• The operational requirements are not in conflict with the available system components/system limitations.
• The system satisfies the operational requirements.
• The system satisfies the needs of the end-user (validation).

2.1. The development process

What is explained above can readily be used within existing systems development processes such as the traditional V-model or agile processes. Note that the iterative and incremental approach for using the three viewpoints of the methodology means that purely sequential processes (such as the waterfall model) are not suited.

The V-model is a model of how a development process can be implemented, and is used here as an example since the model is well-known and easy to understand. The methodology does not make recommendations to what kind of development process should be followed, except for recommending an iterative and incremental process.

An example of how the methodology can be used as part of the V-model development process is given in Figure 2. The different viewpoints involved in the different phases of the development process are colour coded in the illustration.

![Diagram of the V-model development process with colour coding of viewpoints](image-url)
3. The operational viewpoint

This viewpoint concerns the overall design and specification of the operation. This means analysing the operation(s) the system is intended to execute, without considering the physical system in detail. The reasoning behind this viewpoint is both to facilitate a common understanding between system designers and end-users, as well as making sure that the system design will be grounded by the actual operation it is intended to solve.

The operational viewpoint is structured into different sub-categories as shown in Figure 3. Each sub-category is again structured into several sections. These sections are similar, albeit not identical, for each sub-category, and their purpose is explained here:

- **Purpose**
  This section describes the purpose of the sub-category, answering which benefits might be gained from following the outlined principles.

- **Guidelines**
  The guidelines contain the general characteristics of that sub-category, and should give a least-effort description on how to reason about that specific part of the methodology.

- **Key questions**
  This section lists key questions to be taken into account when analysing the current sub-category. These questions try to highlight the central difficulties or trade spaces.

- **Prerequisites**
  This section lists the prerequisites needed in order to reason about the current sub-category in the most meaningful way. Such requirements can include e.g. certain information to be made available or restrictions imposed that need to be considered beforehand.

- **Methods**
  This section lists suggestions for more rigorous methods to follow in order to reason about the methodology.

- **Output**
  The section describes the intended output of the sub-category. If one of the suggested methods is followed, the output will consist of the results from the method. If only the qualitative guidelines and principles as listed in this document are followed, the output from that analysis should correspond to the specifications given here. Some sub-categories, in particular "Analysis of the operation", "Levels of Autonomy" and "Safety and Eventualities", will generate functional and performance requirements. All of these requirements should be gathered in a structured requirement matrix. An example of this matrix is shown in Annex C.

Figure 3 contains a flow chart illustrating the typical work flow of the operational viewpoint. The work starts by analysing and selecting operation concepts in Context definition and the operation in itself in the analysis of the operation, and then incrementally adding details from Levels of Autonomy, Safety and eventualities and Cost effectiveness while iterating over the existing concept and operation description until all necessary detail is accounted for.
3.1. **Context Definition and Operation Concepts**

#### 3.1.1. Purpose

Get an overall description of the concept and highlight concept alternatives. Get information on the context from customer and experts, especially regarding constraints, limitations, and restrictions that might affect the design and implementation. Storyboards can be helpful to visualize the operation in this stage. SWARMS storyboards are presented in D8.1, and an example is given in Annex A.

#### 3.1.2. Guidelines

- Document different plausible concepts for solving the operation.
- Discover constraints/limitations/restrictions arising from considerations such as environmental conditions, ethics, legislation, economics, communication.
  - Constraints should be prioritized, e.g. between rigid and flexible.
• Define what needs to be fulfilled and what is it considered as an accepted result/outcome of the project.
• Document different concept alternatives, and relate them to the constraints.
  o Use a structured decision-making method (see Section 3.1.4) to select the best suited concept.
• This sub-category could be revisited several times during the project design phase, to check whether new information may lead to a different selection of concept.

3.1.3. Key questions

• Are there any environmental constraints?
  o E.g. disability to carry out the operation under certain weather conditions
• Are there any economic constraints that might limit the available design options?
• Are there any special field conditions that need to be taken into account?
  o I.e. on the equipment that is going to be used.
• What are the constraints in available manpower?
• Have ethical and social impacts been taken into consideration?

3.1.4. Methods

• Decision-making methods, such as
  o Potentially all pairwise rankings of all possible alternatives (PAPRIKA) [2]
  o Aggregated Indices Randomization Method (AIRM) [3]
  o Preference Ranking Organization METHod for Enrichment of Evaluations (PROMETHEE) [4]

3.1.5. Output

A document describing the scope of the operation, selection of concept, constraints, limitations, and restrictions, for example as a storyboard (see example in Annex A).

3.2. Analysis of the operation

3.2.1. Purpose

Analyse and break down the operation to show the different sub-operations and tasks the operation consists of, to uncover overall operation modes, design challenges, and needs and limitations regarding autonomous behaviour.

3.2.2. Guidelines

• Define the overall goal of the operation.
• Iteratively break down this goal into sub-operations (or sub-goals).
  o Consider using a time-table, timeline or similar to indicate the timing of sub-operations.
  o Describe the inter-relationships between sub-operations, e.g. sequential, parallel, decision-based, etc.
3.2.3. Key questions

- What are we trying to accomplish?
- Which sub-operations are meaningful to consider?
- What are the success criteria of each sub-operation?
- Which constraints on autonomy do the possibilities for communication entail? Are there any other types of constraints that need to be considered?
- Are there any safety regulations that need to be considered when breaking down the operation?
- What are the time limitations that need to be taken into account?
- What is most important for the (sub-) goals of the operation; efficiency or thoroughness?

3.2.4. Prerequisites

- A clearly defined concept for the operation
- If using an existing system or platform, a description of the system and its capabilities are needed.
- If a new system is to be designed, it is expected that we know a priori some limitations/boundaries/constraints that might exist in terms of money, manpower, hardware etc.

3.2.5. Methods

- Autonomous Job Analysis (AJA) is the recommended method for this analysis. This method is explained in detail in Section 4 and an example is given in Annex B. This method is used because it has been designed especially for autonomous marine operations. On that sense it has an advantage over the other existing methods which are more general and address to different kinds of tasks.
- Alternative methods include
  - Hierarchical task analysis (HTA) [5], and especially the sub-goals template (SGT) extension
  - Applied cognitive work analysis (ACWA) [6].

3.2.6. Output

The output will be a structured description and breakdown of the operation. The analysis should make it easier both for further development and for discussions with different stakeholders. The work done in this sub-category should result in some requirements added to the requirement matrix, see Annex C.
3.3. Levels of Autonomy

3.3.1. Purpose

Specify the degree of autonomy wanted, needed or required during the operation. The term LoA refers to the degree that the system and the operator are able to intervene when an operation is taking place (the extent to which human or machine has the control in different stages of the operation).

3.3.2. Guidelines

- Discover the human-machine collaboration level in each sub-operation. Who should be in charge, operator or machine?
- Use e.g. a "Levels of Autonomy" (LoA) framework as referenced in Section 3.3.5.
- Reveal communication constraints that would affect the level of autonomy of (sub-)operations.
- Decide the desired (maximum/minimum) autonomy level for each sub operation.
- Discover which types of autonomy are relevant to the sub-operation: Autonomy is not just present at the vehicle level, but at different places and in different scales, such as
  - Information processing, information analysis, decision-making, and implementation of actions.
  - Consider dividing (sub-)operations into “functional dimensions” (e.g., information acquisition, analysis, decision and action).
- Discover what affects the LoA in each sub-operation.
- Try to keep the rule for deciding on the LoA as simple as possible.
- Be aware of roles (planner, coordinator, executor, etc.), sub-operations and the coordination between these.
- Try not to finalize on the LoA too early. Take some iterations before coming to a decision.
- Keep safety in mind when choosing the LOA. Remember what are the safety requirements when choosing a level of autonomy.

3.3.3. Key questions

- What is the least/most autonomous each sub-operation can be? This may be governed by e.g. communication or other technological/economic constraints, legislative constraints, environmental restrictions etc.
- Which decisions should be made by the machine/vehicle, and which should be made by the operator? How can the operator be inserted into the loop in an efficient way?
  - Are some decisions associated with high risk, very time-sensitive or high cost? Who is best suited to make the decisions in such circumstances?
- Should the system itself have the permission to change the degree of autonomy?
- Does the selected LoA satisfy all safety requirements?
3.3.4. Prerequisites

- Are there requirements with respect to human-machine collaboration? These may dictate the range of possible levels of autonomy.
- Communication restrictions and technological capabilities in general need to be taken into account before deciding on the LoA.
- Having knowledge of the operation and the expected outcomes since this can help in choosing the correct LoA.

3.3.5. Methods

- Sheridan's Levels of Autonomy or other proposed taxonomies that have been presented by different researchers [7]:
  1. Computer offers no assistance; human does it all
  2. Computer offers a complete set of action alternatives
  3. Computer narrows the selection down to a few choices
  4. Computer suggests a single action
  5. Computer executes that action if human approves
  6. Computer allows the human limited time to veto before automatic execution
  7. Computer executes automatically then necessarily informs the human
  8. Computer informs human after automatic execution only if human asks
  9. Computer informs human after automatic execution only if it decides to
  10. Computer decides everything and acts autonomously, ignoring the human
- LoA extensions such as adaptive automation or adjustable automation [8]

3.3.6. Output

A structured proposal on the degree of autonomy used throughout the operation. The work done in this sub-category should result in some requirements added to the requirement matrix, see Annex C.

3.4. Safety and Eventualities

3.4.1. Purpose

Make sure the operation can be performed at a defined, acceptable level of safety. Make sure events outside normal operation (eventualities) are documented and can be mitigated in the best possible manner.

3.4.2. Guidelines

- Find out what kinds of hazard events exist that could jeopardize the safety of operation/sub-operations. Try to find if some actions can be taken a priori in order to decrease the risk of hazard events happening.
- Divide between the types of events that can be regarded as eventualities (events possibly leading to altering the operation) and the types of events that lead to breach of safety.
Eventualities are of special importance with respect to implementation of autonomous functionalities.

- Describe how eventualities can be mitigated, either proactively or after they have been detected.
- Describe operational safe states.
  - Document possible conditions where going to an operational safe state should be considered.
- Quantify the risk levels and decide what the acceptable risk is.
- Discover how risks in a sub-operation can affect the overall operation. In which manner are they connected?
- Experts and clients can have a good overview of matters that can play a significant role.
- Suggested quantification of risk will be added as risk matrix in v2.

### 3.4.3. Key questions

- What are the hazards related to the operation?
- What are the risks associated with the hazards, and are the risks at an acceptable level?
  - How can the risks be reduced to acceptable levels?
- Which unforeseen events can happen during the operation?
- Which operational safe states (ref. nomenclature) can be defined for the operation?
- Which actions can be undertaken in order to guarantee the safety of the operation?

### 3.4.4. Prerequisites

- Any type of event that jeopardizes the safety of the operation needs to be taken into account.
- A detailed analysis of each sub-operation needs to be available.
- A structured way of classifying safety with respect to risk and consequence should be agreed upon.

### 3.4.5. Methods

- Risk analysis methods
  - Hazard Identification (HAZID) [9]
  - Hazard Operability Analysis (HAZOP) [10]
  - Job Safety Analysis (JSA) [11]

### 3.4.6. Output

- A description of the possible risks and eventualities that might happen during an operation.
- A description of necessary safety measures and eventuality mitigations for the operation and the sub-operations.
- The work done in this sub-category should result in some requirements added to the requirement matrix, see Annex C.
3.5. **Cost effectiveness**

3.5.1. **Purpose**

Measure the positive and negative consequences of choices related to an operation and assess the intrinsic value of project alternatives.

3.5.2. **Guidelines**

- Set a context for the analysis, for instance whose cost and benefits should be recognized.
  - Remember to assess the choices made regarding degree of autonomy.
- Identify and categorize costs and benefits.
- Predict outcome of cost and benefits over relevant time period.
- Convert all costs and benefits into a common currency, and into present values.
- Prioritize costs and benefits.
- Compute a cost-effectiveness ratio or net present value.
- Consider studying how the uncertainty of the output relates to sources of uncertainty in the inputs (sensitivity analysis).
- Use information available in the previous stages that can influence your analysis.
- Include possible time limitations in the analysis.

3.5.3. **Key questions**

- What are the costs and benefits of developing compared to buying?
- What are the cost and benefits of a manned operation compared to development of autonomy for the same operation? Consider several levels of autonomy.
- Are there safety, security, legislative or other requirements that can add to the cost?
- What is acceptable to lose during the operation?

3.5.4. **Prerequisites**

- Call for tenders/request for quotation on services and goods.
- Estimate of investment costs, installation costs, activity costs and maintenance costs.
- Estimate of improved safety, productivity or workload reduction by autonomy.
- Be able to express all effects in pecuniary terms.

3.5.5. **Methods**

- Life Cycle Costing (LCC) and Total Cost of Ownership (TCO) can be used to highlight the cost side.
- To analyse the ratio of money or resources gained or lost on an investment relative to the amount of money or resources invested, Return On Investment (ROI) can be used.
- Non-monetary effects are considered in Cost-Utility-Analysis (CUA) with the objective to point out the best among several alternatives.
3.5.6. Output

An evaluation of costs and benefits regarding the operation. This evaluation may act as baseline for a next iteration re-evaluating the choices made in category A.
4. Autonomous Job Analysis (AJA)

In Section 3.2.5 there is a reference to Autonomous Job Analysis Method. This method has been created within SINTEF as part of the SEATONOMY methodology [1] and its principles are based on the Hierarchical Task Analysis (HTA), which is considered as the “best known task analysis technique” [12]. Since the first paper written on the specification for the method in 1967, the past 48 years have seen many developments in ergonomics research and methods but HTA has remained a central approach. It is fitting to review the current state of the art to help take stock of where HTA has come from, the contemporary issues, and the potential for the future. When using the task analysis technique as a method for breaking down an operation, “there is a tendency to fall into the trap of writing down the series of steps a human takes”, [5]. The correct way to analyse a task according to Sheridan [7] is to “specify the information required, the decisions to be made, the control actions to be taken”. The new method, called Autonomous Job Analysis (AJA), is intended to uncover overall operational modes, design challenges, needs and limitations regarding autonomous behaviour for marine operations. The AJA method is one of the suggested methods, which provides a structured approach for design, development and validation of mobile autonomous maritime operations and systems. AJA is a method to be used in the operational viewpoint, which concerns the overall design and specification of the operation. The task analysis elements in [13] includes task description, behaviour modelling, risk assessment, hypothesis generation and cost-benefit analysis. We have chosen an iterative manner to keep the analysis to a manageable size, at the cost of perhaps having to perform the analysis over several iterations, including iterations where new information from other methods are taken into account. A diagram showing the different design phases in an engineering project is presented in Figure 4. It is indicated where AJA is most appropriate to be used.

4.1. Requirements and advices to be followed

The main purpose of the AJA method is to aid the design of autonomous marine operations by uncovering the overall operational modes and design challenges as well as needs and limitations related to autonomous behaviour by breaking down operations into sub-operations and tasks and analysing these individually. As a result, the method facilitates a common understanding between all stakeholders. For an autonomous operation related to oil- and gas the stakeholders could for instance be:

- An oil company that needs the operation to be executed.
- An oil service company carrying out the physical operation.
- A company designing the autonomous operation.
- One or more companies developing the system needed to execute the operation.

There is not always a distinction like this, and the stakeholders could for instance all be from the same company. AJA may not only be used when designing new autonomous marine operations, but also for analysing existing marine operations. AJA can reveal possible design flaws or be used as a tool for design improvements. AJA is a team effort and requires close cooperation between people with different competence and backgrounds for best results. This will help designers in defining the correct goals and reach the desired result. Prior to AJA a unified understanding between all stakeholders of what the AJA is trying to achieve should be established. This could for instance be achieved by distributing a brief description of AJA, containing the main elements from this section.
4.2. Guidelines to be followed

When performing the analysis a meeting is required which is called the AJA meeting. The form of the meeting is motivated by the form of meetings used for HaZard and Operability studies (HAZOP), which is “a structured and systematic examination of a planned or existing process or operation in order to identify and evaluate problems that may represent risks to personnel or equipment, or prevent efficient operation” [10] The main goal of the AJA meeting is to gather and share all available information concerning the operation in question through cooperation between stakeholders. This information is then structured and gathered in a detailed list for sharing. The information can include, but is not limited to, constraints, limitations, restrictions regarding the software/hardware, money, human resources, and any kind of available information that can affect the design or the implementation of the operation.

A proposed agenda for the meeting can be as follows:
1. Introduction and presentation of participants.
2. Presentation of the main goal(s) of the operation.
3. Presentation of the AJA method.
4. Recapitulate the context definition and operation concepts.
5. Perform AJA (as far as possible).
6. Agree on further actions.

The meeting is driven by the moderator who is responsible for:
- Introducing the method to the client.
- Leading the discussion.
- Ensure completeness of the analysis.

The moderator could be from the team designing the operation, or hired from an external company specializing in leading these kinds of meetings. It can for instance be desirable to use an independent third party which does not favour either of the stakeholders.

The secretary is responsible for:
- Preparation of the AJA table, see Table 2.
- Recording the discussion.
- Version control of the AJA table/flow chart.

The AJA table consist of a series of questions to be answered. The meeting participants should be experts within various aspects of the operation. Meetings including a large number of participants
tend to become inefficient and hard to manage. If it is likely that the total number of participants needed exceeds 8-10, then dividing into smaller meetings should be considered. The responsibilities of the participants are the same as for participants as HAZOP meetings:

- Be active! Everybody’s contribution is important.
- Be to the point. Avoid endless discussion of details.
- Be critical in a positive way: not negative, but constructive.
- Be responsible. The person who knows should let others know.

It is unlikely that all questions can be answered during a single AJA meeting even if the total number of participants is kept low. 'Further actions‘ could therefore be to choose one or more responsible to actively seek out the relevant or missing information through experts or written material. The AJA table should be updated with this new information, or at least with reference to documentation available elsewhere, before it is distributed among the stakeholders. The person(s) responsible can be chosen from the operation design team, or from the client's team. The client may have relevant experts in his/her company, even if these experts did not attend the AJA meeting. If a large operation is to be analysed, it may be necessary to perform AJA over several meetings. This gives the opportunity to include new or additional experts to add different perspectives of the operations.

It is important that new participants are brought up-to-date before the meeting in order not to waste time. In the beginning of the meeting the requirements/context specification should be agreed on.

The Autonomous Job Analysis consists of the following steps:
1. Describe the main goal of the operation
2. Divide into sub-goals, based on e.g. sequence, parallel behaviour or choices
3. Answer the list of AJA questions described in Table 2.
4. For each sub-goal, go to step 2 and repeat until goals become trivial tasks

The following steps are required during post processing:
1. The details from the AJA meeting should be processed and distributed among the stakeholders.
2. The stakeholders give feedback for possible subsequent iterations.

Another fact that needs to be considered is the presentation of the AJA method by the moderator. Describing an operation in a clear and informative way is challenging. Different authors prefer different template representations when describing operations. A variation between tables, lists, flowcharts have been proposed and the most common templates are presented in [10], [5]. In the SEATONOMY methodology, the table representation has been proposed, followed by a flowchart to show the main progression of an operation. An example of this table for SWARMS storyboard 2 is given in Annex A.

### 4.3. AJA table formulation

The AJA table consists of rows representing goals and sub-goals, as well as the questions to facilitate a detailed analysis of the operation under evaluation. The rows under goals or sub-goals are called “Communication”, “Perception”, “Success Criteria”, “What can go wrong”, “What is the operational safe state”, “Levels of Autonomy”, “Other premises/requirements” and “Notes”. These aspects are clarified in Table 2: Questions to the AJA-table. Depending on the operation and the available information, the table can be modified by adding or removing questions as necessary.
4.4. Output

The output is a structured description and breakdown of the operation with each sub-operation is individually analysed based on technological and operational constraints uncovered by the AJA meeting. See the example in Annex B.

<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Description of the sub-goal</td>
<td>Give a short description of the sub-goal, focusing on the objective without too much technical detail. Achievement of the sub-goal should contribute to the achievement of a goal at a higher level, and eventually the main goal of the operation.</td>
</tr>
<tr>
<td>2</td>
<td>Communication</td>
<td>Communication flow: What key information needs to be communicated and when? Communication restrictions: What are the limitations?</td>
</tr>
<tr>
<td>3</td>
<td>Perception</td>
<td>Which information about the environment and the system itself must be available</td>
</tr>
<tr>
<td>4</td>
<td>What are the criteria for success?</td>
<td>List design criteria which specify whether the sub-goal has been achieved. This can, for instance, be performance specifications related to accuracy or time.</td>
</tr>
<tr>
<td>5</td>
<td>What can go wrong?</td>
<td>Is there everything that can prevent the sub-goal from being successfully accomplished? Be specific about what characterizes abnormal behavior.</td>
</tr>
<tr>
<td>6</td>
<td>What is the operational safe state?</td>
<td>Define what state of mode the system should go to in order to maintain the safety of the operation in the best possible way.</td>
</tr>
<tr>
<td>7</td>
<td>What is the human machine interaction?</td>
<td>Describe the human-machine interaction. The interaction can be described in words, or with reference to some taxonomy Levels of Autonomy.</td>
</tr>
<tr>
<td>8</td>
<td>Are there other premises or requirements for successful execution?</td>
<td>Describe other relevant premises for successful execution of the sub-goal.</td>
</tr>
<tr>
<td>9</td>
<td>Notes and comments</td>
<td>Add comments that are relevant for the sub-goal, but are not captured by the previous questions or table.</td>
</tr>
</tbody>
</table>
5. References


[8] M. Vagia, A. Transeth and S. Fjerdingen, “A literature review on the levels of automation during the years. What are the different taxonomies that have been proposed?,” *Applied ERgonomics*, p. InPress, 2015.


Annex A. Example storyboard: SB2
Monitoring of chemical pollution

The following storyboard is copied from a preliminary version of D8.1. It may not be up to date with the final version in D8.1.

The objective of the Use Case related with this Storyboard is to monitor a given area of the sea at different depths for harmful concentration of Hydrogen Sulphide \([H_2S]\). All the data collected during the inspection will generate a map with relevant information provided by the \(H_2S\) probe for the specific area. The Storyboard has different stages to be developed.

**Stage 0: SWARM’s mission planning**
*Actors:* Command and Control Centre  
*Actions to be done:* Planning and conditions for re-planning.

**Stage 1: Deployment of AUVs/ROVs swarm and start and acoustic map**
*Actors:* Support vessel, AUVs  
*Actions to be done:* A determinate number of AUVs, two or three, will be deployed in order to be coordinated for scanning the area (the geographical area of interest in which was detected the chemical pollutant). A possible situation of mapping is shown below. The way to develop the whole mapping will depend on restrictions of time (endurance), sensors and space (operational range), this means that multiple AUVs can be deployed in order to map the underwater profile.

![AUVs monitoring the seabed while support vessel finish the deployment](image)

**Fig. 1-** AUVs monitoring the seabed while support vessel finish the deployment
Stage 2: Acoustic map

**Autors:** Support vessel, AUVs

**Actions to be done:** Once the AUVs have completed the mapping, the data from the scanning will provide the current representation of the sea floor along with the dangerous area for the underwater equipment.

Depending on the number of deployed AUVs, two cases are possible: case A with 3 AUVs and case B with 2 AUVs. In the first case, which uses 3 AUVs, these will collaborate to generate a high quality underwater map: the upper AUV will map a greater area with a low accuracy, and the two AUVs from below will map a smaller area with a higher accuracy. In the second case, which uses 2 AUVs, these will collaborate in order to map a greater area in the shortest time, generating a standard quality underwater map.

![Image](https://example.com/image.png)

**Fig. 2:** All the AUVs monitoring the seabed and representing an acoustic map

Stage 3: Deployment of AUVs/ROVs. Measurements

**Autors:** Support vessel, AUVs, ROVs

**Actions to be done:** Using the map generated at Stage 2, multiple AUVs/ROVs will be deployed in order to scan the concentration of H₂S and inspect the underwater flora and fauna at different depths.

The measurement and inspection will be made as a collaborative effort between 3 AUVs/ROVs in the following situation: One AUV/ROV will measure the concentration on different depths, and the second AUV/ROV will follow the first one at a safety distance in order to visually inspect the biological impact of the chemical pollutant. The third ROV can be used to inspect in detail other interest area (proximity area of H₂S mapping). The second AUV/ROV will provide high quality live video streaming. Also, multiple cameras from other ROVs can be used for a greater field of view of the underwater flora and fauna.
Stage 4: Deployment of AUVs/ROVs for statistics
Actors: AUVs, ROVs
Actions to be done: Using the measurements from Stage 3 a data set of location, depth and H₂S concentration [GPS position; depth; % H₂S] is generated. The result is interpreted with possible archived measurements. Also the data set is used for future monitoring which can occur after a determined period of time or extreme weather.

![Analysing underwater environments for statistics](image)

Stage 5: Recovery operations
Actors: Support vessel, AUVs, ROVs
Actions to be done: When the measurements operations have been done, the whole AUVs and/or ROVs should be directed to the support vessel to finish the actuation over the windmill.
The following list is the ideal quantity of vehicles to be used in this Storyboard:

- AUV: 3
- ROV: 4
- USV: 1
- Support vessel: 1

What is the role of each kind of vehicle?

- **AUV**: The AUVs will be in charge of mapping the entire seabed in order to characterize the underwater environment. Together with ROVs, the AUVs will be used for performing the measurements.
- **ROV**: ROVs will measure the concentration of H2S contained in the water.
- **USV**: USV will work like a relay in order to ease all underwater to surface communications.
- **Support Vessel**: The support vessel will transport all the required equipment, robotic vehicles and will supervise all the operatives.
## Annex B. Example AJA-table

Below is an example of an AJA-table for SWARMs storyboard 2.

<table>
<thead>
<tr>
<th>Autonomous Job Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main goal of operation:</strong></td>
</tr>
<tr>
<td><strong>ID</strong></td>
</tr>
<tr>
<td>2.1</td>
</tr>
<tr>
<td>Communication</td>
</tr>
<tr>
<td>Perception</td>
</tr>
<tr>
<td>Success criteria</td>
</tr>
<tr>
<td>What can go wrong?</td>
</tr>
<tr>
<td>What is the oper. safe-state?</td>
</tr>
<tr>
<td>HMI</td>
</tr>
<tr>
<td>Other premises/requirements</td>
</tr>
<tr>
<td>Notes/comments</td>
</tr>
</tbody>
</table>

### 2.2 Description of sub-goal

#### Deployment of AUV SWARM

| Communication | Ability to communicate within the swarm and with the operator, sending their own position. |
| Perception | Ability to find their own position. |
| Success criteria | Find the correct starting position. |
| What can go wrong? | Collision with themselves/seabed/other vessels/vehicles, communication errors, hardware/software malfunctioning, unexpected weather conditions. |
| What is the oper. safe-state? | Automatically go to the surface in case any error condition occurs, try to communicate any problem to the operator and other vehicles as well. |
Title: D2.1 Operation analysis method
Status: Draft
Dissemination level: CO

<table>
<thead>
<tr>
<th>HMI</th>
<th>Operator should be able to monitor the AUVs all the time, position and status. Operator should have the ability to intervene at any time (abort or change mode). In addition to the operator doing the deployment, another operator should be located at the operator station for control and surveillance.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other premises/requirements</td>
<td>Frequency collisions, permissions needed from local authorities for being in the sea</td>
</tr>
<tr>
<td>Notes/comments</td>
<td></td>
</tr>
</tbody>
</table>

### 2.3 Description of sub-goal

**Mapping of the section/area**

**Communication**

Own position and status of AUVs and barymetric data. Ability to communicate within the swarm and with the operator, operator mode selection.

**Perception**

Underwater positioning system for their own positioning, Doppler for velocity, sonars for depth mapping and collision avoidance (either with other vehicles or seabed).

**Success criteria**

Traverse the designated area, measure depth, construct topographical map of the seabed.

**What can go wrong?**

Communication failure, sensors failures, collision, Hardware errors, Software Failures, change in the sea state, loss of actuation, power loss, water intrusion, battery drainage, not able to complete the survey in a specified time, AUV leaves the designated area.

**What is the oper. safe-state?**

Automatically go to the surface in case any error condition occurs, try to communicate any problem to the operator and other vehicles as well.

**HMI**

The operator at the operation station should be able to monitor the AUVs all the time, position and status. Operator should have the ability to intervene at any time (abort or change mode).

**Other premises/requirements**

Stay within the designated area (AUV), time requirement TBD, resolution requirement TBD

**Notes/comments**

This subgoal happens for several AUVs in parallel. Barymetric measurements may come from AUVs, USV or the support ship itself. Shallow water measurements are most efficiently done by surface vessels, manned or unmanned.

### 2.4 Description of sub-goal

**Data Reporting**

**Communication**

Mapping of the section/area

**Perception**

N/A

**Success criteria**

Transmitted data received at the operator station.

**What can go wrong?**

Communication breakdown, interference with other devices, bandwidth problems (too much information sent at the same time, distance of the AUVs from the base can also lead to communication problems), obstruction of the transmission i.e. underwater mountain, hardware failures i.e. receiver. Surface node malfunctions.
<table>
<thead>
<tr>
<th>What is the oper. safe-state?</th>
<th>Resending the data, automatically or operator initiated, go to the surface so that the data can be manually collected by the operator.</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMI</td>
<td>Possibility to select transmission modes/parameters</td>
</tr>
<tr>
<td>Other premises/requirements</td>
<td>Check if there any frequency collisions.</td>
</tr>
<tr>
<td>Notes/comments</td>
<td></td>
</tr>
</tbody>
</table>

**2.5 Description of sub-goal**

**Deployment of ROV(s)**

<table>
<thead>
<tr>
<th>Communication</th>
<th>Ability to communicate within the swarm and with the operator, send their own position.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perception</td>
<td>Ability to find their own position.</td>
</tr>
<tr>
<td>Success criteria</td>
<td>Find the correct starting position.</td>
</tr>
<tr>
<td>What can go wrong?</td>
<td>Collision with themselves/seabed/other vessels/vehicles, communication errors, hardware/software malfunctioning, unexpected weather conditions.</td>
</tr>
<tr>
<td>What is the oper. safe-state?</td>
<td>Go to the surface in case any error condition occurs, try to communicate any problem to the operator and other vehicles as well.</td>
</tr>
<tr>
<td>HMI</td>
<td>Operator should be able to monitor the ROVs all the time, position and status. Operator should have the ability to intervene at any time (abort or change mode). In addition to the operator doing the deployment, another operator is needed for control of the ROV.</td>
</tr>
<tr>
<td>Other premises/requirements</td>
<td>Frequency collisions, permissions needed from local authorities for being in the sea</td>
</tr>
<tr>
<td>Notes/comments</td>
<td></td>
</tr>
</tbody>
</table>

**2.6 Description of sub-goal**

**Measure concentration of H2S**

<table>
<thead>
<tr>
<th>Communication</th>
<th>Communication is handled by parallel sub-goals.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perception</td>
<td>H2S sensor</td>
</tr>
<tr>
<td>Success criteria</td>
<td>Measure of H2S concentration in different depths</td>
</tr>
<tr>
<td>What can go wrong?</td>
<td>Communication breakdown, interference with other devices, bandwidth problems (too much information sent at the same time, distance of the AUVs from the base can also lead to communication problems), obstruction of the transmission (i.e., underwater mountain), hardware failures (e.g., receiver, cable collision, H2S sensor failure), ROV cable limitations if the area is too large. Communication errors apply in case we send the information real-time. If the AUV just collects the information needed and then the operator has to retrieve it by himself then this is not needed.</td>
</tr>
<tr>
<td>What is the oper. safe-state?</td>
<td>Automatically go to the surface in case any error condition occurs, try to communicate any problem to the operator and other vehicles as well. For communication problems: Try to resend data, go to the surface for manual collection of the data</td>
</tr>
<tr>
<td>HMI</td>
<td>Operator should be able to monitor the ROVs all the time, position and status. Operator should have the ability to</td>
</tr>
</tbody>
</table>
### 2.7 Description of sub-goal

**Follow another AUV and inspect flora and fauna**

**Communication**
- Ability to communicate within the swarm and with the operator, send their own position, live streaming video.

**Perception**
- Camera, position of leading vehicle.

**Success criteria**
- Video of such quality that flora and fauna can be inspected. The area that is filmed is relevant compared to the pollution measurements.

**What can go wrong?**
- Communication breakdown, interference with other devices, bandwidth problems (too much information sent at the same time), hardware failures (e.g., receiver, cable collision), cable limitations if the area is too large, bad quality of video (i.e., weather conditions, small bandwidth can also cause transmission of poor images).

**What is the oper. safe-state?**
- Resending the data, go to the surface if anything unexpected arrives, go to the surface to manually collect the data

**HMI**
- In addition to inspect videos, the operator at the operator station should be able to monitor the ROVs all the time, position and status. Operator should have the ability to intervene at any time (abort or change mode).

**Other premises/requirements**
- Safe distance from the first vehicle, permissions needed from local authorities for being in the sea

**Notes/comments**
- Running in parallel with subgoal 6

### 2.8 Description of sub-goal

**AUV recovery Operation**

**Communication**
- All vehicles should receive and acknowledge the end-of-mission command.

**Perception**
- Position system to be working so that they go to the recovery point.

**Success criteria**
- AUVs recovered safely.

**What can go wrong?**
- Strong current. High waves. AUV did not reach the recovery point.

**What is the oper. safe-state?**
- Depending on the environmental conditions, the safe state can either be lying at the bottom or floating at the surface.

**HMI**
- Abort command. Map positions. At least two operators may be involved. One at the operator station for control and surveillance, one at deck.

**Other premises/requirements**
- NA

**Notes/comments**
- Starts at timeout or abort command from operator
<table>
<thead>
<tr>
<th>Description of sub-goal</th>
<th>AUV Manual operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication</td>
<td>Receive operator commands, report back position and status.</td>
</tr>
<tr>
<td>Perception</td>
<td>Underwater positioning system for their own positioning, Doppler for velocity, sonars for depth mapping and collision avoidance (either with other vehicles or seabed).</td>
</tr>
<tr>
<td>Success criteria</td>
<td>Operator has full control of the AUV.</td>
</tr>
<tr>
<td>What can go wrong?</td>
<td>Collision with themselves/seabed/other vessels/vehicles, communication errors, hardware/software malfunctioning, unexpected weather conditions.</td>
</tr>
<tr>
<td>What is the oper. safe-state?</td>
<td>Automatically go to the surface in case any error condition occurs, try to communicate any problem to the operator and other vehicles as well.</td>
</tr>
<tr>
<td>HMI</td>
<td>The operator is located at the operator station. Operator should be able to give manual commands. Operator should be able to monitor the AUVs all the time, position and status. Operator should have the ability to intervene at any time (abort or change mode).</td>
</tr>
<tr>
<td>Other premises/requirements</td>
<td>NA</td>
</tr>
</tbody>
</table>
Annex C. Requirements matrix

In the requirements matrix the use of the word “shall” denotes requirements that must be met. Use of the word “should” denotes requirements that are desirable and must be met unless justification is provided for an alternative. Use bold for "shall" and "should". Each requirement shall only contain one "shall" or "should".

Use TBC (To Be Completed) or TBD (To Be Defined) in order to write precise requirements even though all details are not in place. For example: "Accuracy shall be TBC".

Text in italic is used to separate comments, design issues and reasoning from requirements. This helps writing requirements short and precise and still the reader gets the context.

The requirements are grouped according to the following definitions:

- **VEH** – Vehicle requirements. That is AUVs, ROVs and ASVs.
- **HMI** – User interface and control station requirements.
- **COM** – Communication requirements.
- **INT**- Distributed intelligence, typically mapping, cooperation algorithms etc.
- **GEN** – General requirements that does not fit into any of the other categories.

**Req. No.**

Requirement numbers shall start with the group followed by a unique number. Derived requirements (if any) have an additional number. For example: GEN-1-1 is the first derived requirement to requirement GEN-1. Requirements numbers may be changed in final version of documents. Letters may be used in early document versions in order to present requirements in a logical order. For example GEN-1, GEN-1a, GEN-2, GEN-2a, GEN-2b, GEN-3 etc.

**Origin:**

The task and partner that first wrote the requirement shall be noted in the origin column.

**Implementation:**

The columns for implementation are indicative and subject to discussions among partners. Formal responsibility is described in the Description of Work.

**Test Reference:**

Indicate the demonstrator location where the requirement will be demonstrated. All requirements will probably not be demonstrated in all locations. Later in the project the marks might be replaced by references to test procedures if this is considered useful.

Table 3 shows an example of a requirement matrix. This version is not final (partner comments are not incorporated) and should be read as an example only.
### Table 3: Example requirement matrix

<table>
<thead>
<tr>
<th>Req. no.</th>
<th>Description</th>
<th>Origin</th>
<th>Implementation</th>
<th>Test Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Task</td>
<td>Partner</td>
<td>Task Partner</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GC</td>
<td>ROM</td>
<td>NOR</td>
</tr>
</tbody>
</table>

#### Vehicle equipment (VEH)

| VEH-1 | AUVs/ROVs/ASVs **shall** have the ability ego-localization with accuracy minimum **TBD** horizontally and **TBD** vertically. | 2.1/8.1 | SINTEF |
|       | Comment: The accuracy will probably be given by the equipment available, not by demonstrator needs. |        |       |
| VEH-2 | AUVs/ROVs/ASVs **shall** detect internal faults and error states. | 2.1/8.1 | SINTEF |
|       | Comment: **Battery status included.** |        |       |
|       | Comment: **Self-test functions may vary between units.** |        |       |
| VEH-3 | AUVs/ROVs/ASVs **shall** react to internal faults and error states. | 2.1/8.1 | SINTEF |
|       | Comment: **Some errors might invoke safe state.** |        |       |
| VEH-4 | The middleware in the vehicles **should** run on the same embedded computer with interface to the HW already on board the vehicles. | 2.1/8.1 | SINTEF |
|       | Comment: **Unless it is considered easier to integrate into the already existing computer when all aspects, also verification, are taken into consideration.** |        |       |
| VEH-5 | All data **should** be stored in the vehicle for eventual retrieval after the mission is finished. | 2.1/8.1 | SINTEF |
| VEH-6 | The vehicle **shall** be able to operate for minimum **TBD** minutes. | 2.1/8.1 | SINTEF |
| VEH-6a | The middleware implementation running on the vehicle **shall** be designed with energy efficiency in mind. | 2.1/8.1 | SINTEF |
|       | Comment: **Rationale is to save battery.** |        |       |

#### User Interface / Control Station (HMI)

| HMI-1 | The operator **shall** be able to abort the operation. | 2.1/8.1 | SINTEF |
| HMI-2 | The operator **shall** be able to interfere with the operation. | 2.1/8.1 | SINTEF |
### Title: D2.1 Operation analysis method

**Status:** Draft  
**Dissemination level:** CO

<table>
<thead>
<tr>
<th>Req. no.</th>
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<th>Test Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Comment:</strong> This could be to abort the operation, change modes etc. Modes are described elsewhere.</td>
<td></td>
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<tr>
<td>HMI-3</td>
<td>The operator <strong>shall</strong> be able to monitor all transmitted data from all vehicles.</td>
<td>2.1/8.1</td>
<td>SINTEF</td>
<td></td>
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<tr>
<td>HMI-4</td>
<td>The age of the data <strong>shall</strong> be presented or visualized to the operator.</td>
<td>2.1/8.1</td>
<td>SINTEF</td>
<td></td>
</tr>
<tr>
<td>HMI-5</td>
<td>The operator <strong>shall</strong> be given a warning if an abnormal situation occurs. <strong>Comment:</strong> Could be an alarm or just a colour.</td>
<td>2.1/8.1</td>
<td>SINTEF</td>
<td></td>
</tr>
<tr>
<td>HMI-6</td>
<td>The operator <strong>shall</strong> see the vehicle positions in a sea map.</td>
<td>2.1/8.1</td>
<td>SINTEF</td>
<td></td>
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<tr>
<td>HMI-7</td>
<td>The operator <strong>should</strong> be able to collect data from vehicles manually after the operation. <strong>Comment:</strong> Might not be necessary to implement for the demonstrators.</td>
<td>2.1/8.1</td>
<td>SINTEF</td>
<td></td>
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<tr>
<td>HMI-8</td>
<td>It <strong>should</strong> be possible to use manually collected data together with real time collected data (data fusion). <strong>Comment:</strong> For example to present all data collected inside the same map.</td>
<td>2.1/8.1</td>
<td>SINTEF</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Comment:</strong> Might not be necessary to implement for the demonstrators.</td>
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<tr>
<td></td>
<td><strong>Communication (COM)</strong></td>
<td></td>
<td></td>
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<tr>
<td>COM-1</td>
<td>One communication standard <strong>should</strong> be used.</td>
<td>2.1/8.1</td>
<td>SINTEF</td>
<td></td>
</tr>
<tr>
<td>COM-2</td>
<td>Communication between vehicles <strong>shall</strong> be possible via other vehicles. <strong>Comment:</strong> Rationale: To increase the range.</td>
<td>2.1/8.1</td>
<td>SINTEF</td>
<td></td>
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<tr>
<td></td>
<td><strong>Comment:</strong> Like a dynamic mesh network. Several possible implementation solutions exist. Be aware of bandwidth limitations.</td>
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<tr>
<td>COM-3</td>
<td>Cyclic data periods <strong>shall</strong> be configurable for different types of data. <strong>Comment:</strong> Rationale: Bandwidth may vary from location to location.</td>
<td>2.1/8.1</td>
<td>SINTEF</td>
<td></td>
</tr>
</tbody>
</table>
### COM-4

There **should** be a possible to detect and cope with bandwidth problems.  
*Comment: This might for example imply to turn off camera live streaming.*

### COM-5

AUVs/ROVs/ASVs **shall** as a minimum transmit the following data:
- Ego localization results (typically own position)
- Sensor data
- Selftest results (including battery status)
- Actual Mode

*Comment: Sensor data (including camera) may vary between different vehicles.*

*Comment: Ego-monitoring includes useful information from communication modems.*

### COM-6

AUVs/ROVs/ASVs **should** as a minimum receive the following data:
- Mode selection
- Trajectory to be followed or area to be surveyed
- Timing requirements
- Manual control commands (in manual mode)

### Distributed Intelligence (INT)

The following general modes **shall** be implemented in the AUVs:
- Manual mode
- Go to surface
- Go to safe state

*Comment: This requirement looks like a design decision. However, the*
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</table>
| INT-2   | The following modes **should** be implemented in the AUVs:  
- Stop/Hoover  
- Go to Position  
- Battery save mode.  
*Comment: Battery save mode is not necessary for the demonstration.* | 2.1/8.1 | SINTEF | |
| INT-3   | Upon loss of communication for **TBD** minutes, the AUV **shall** go to safe state. | 2.1/8.1 | SINTEF | |
| INT-4   | Upon loss of communication for **TBD** minutes, the AUV **should** search for a position where communication is possible. | 2.1/8.1 | SINTEF | |
| INT-5   | Upon low battery, the AUV **shall** go to safe state. | 2.1/8.1 | SINTEF | |
| INT-6   | A timeout function activating **shall** go to safe state **shall** be implemented. | 2.1/8.1 | SINTEF | |
| INT-7   | Safe state **should** be:  
- Go to surface and  
- Report own position, battery status and mode at a predefined interval.  
*Comment: Interval may be seldom in order to save battery.*  
*Comment: Surface is not safe if there is a ship with propellers at the surface.* | 2.1/8.1 | SINTEF | |
| INT-8   | Obstacle avoidance **should** be implemented if required sensors are available. | 2.1/8.1 | SINTEF | |