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Report

Study of the Advantages and Disadvantages of Shore-Based ROV Inspections and Operations on Subsea Facilities

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SUMMARY
This study investigates the development of non-conventional concepts for inspection, maintenance, and repair (IMR) using remotely operated vehicles (ROVs), with particular focus on shore-based control rooms and implications for integrity assessment of subsea facilities. The increased use of such concepts leads to lower carbon footprint, improved working environment, and greater flexibility. Challenges are related to communication quality, the data basis for integrity assessments, access to tools, and the need for robust procedures and training.

It is recommended to ensure that the choice of ROV-IMR concept is suitable for the criticality of the operation, to strengthen training and procedures in line with Human Factors and Man-Technology-Organisastion-principles, and to follow up on communication quality as a critical factor. Further work should focus on experiences from ROV pilots, new technology, and the evaluation of IMR inspection methods.

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This report was prepared with limited AI assistance when translating the report from Norwegian to English. The authors thoroughly evaluated the material and accept complete responsibility for the content presented.

Executive Summary

The purpose of this report is to examine the development of non-conventional concepts for Remotely Operated Vehicles (ROV) Inspection, Maintenance and Repair (IMR), with a particular focus on shore-based control rooms (Remote Operations Centres – ROC) and the potential consequences these may have for the integrity assessment of subsea facilities.

The background for this work is the Norwegian Ocean Industry Authority's (Havtil) efforts to strengthen risk-based follow-up of subsea operations in line with the Activity Regulations and the Management Regulations. There is an increasing use of non-conventional ROV-IMR-solutions, particularly the use of shore-based ROCs. This development offers both opportunities and new challenges that must be addressed. The industry is positive towards the technological development and emphasizes that the right tool must be used for the right situation.

This report is based on:

- A review of international and national (Norwegian) literature.
- Interviews with industry stakeholders (oil and gas operators, service providers, system suppliers).
- A holistic assessment of the concepts and their development through a man-technology-organization (MTO) perspective, based on the collected knowledge base.

Most non-conventional ROV concepts, such as the use of unmanned surface vessels, temporary/permanent subsea garages, and ROVs deployed from shore, are currently under testing, trials and qualification. Shore-based control of ROVs that have been deployed from IMR vessels is common practice. Some concepts are already in use on a limited scale.

Strengths of non-conventional ROV-IMR concepts are:

- Lower carbon footprint and cost.
- Improved working environment for operators.
- Increased flexibility in staffing and operations.

Moving control rooms onshore results in changes in workflows, collaboration, and situational awareness. Strong user involvement (pilots, inspectors, technicians, and subject matter experts) is essential to ensure that the solutions work effectively in practice.

Possible challenges of non-conventional ROV-IMR concepts include:

- Communication quality (latency, bandwidth, data loss).
- Loss of communication with the ROV may cause delays in IMR inspections and interventions, with potentially negative impacts on asset integrity.
- Changes in data quality, which may affect the basis for integrity assessments.
- Availability of tools and maintenance capabilities with some non-conventional ROV-IMR concepts.
- Need for robust procedures and training to support new operational approaches.

Recommendations for further development of non-conventional ROV-IMR concepts are to:

- Ensure that the choice of ROV concept suits the criticality of the operation and integrity requirements, to ensure high-quality integrity assessments.
- Strengthen procedures, training, and testing in line with Human Factors and MTO principles.
- Actively involve users in the development of the concepts.
- Follow up communication quality as a key element in design and operations.

This will provide the foundation for ensuring that the development of non-conventional ROV-IMR concepts supports a strengthened and more effective integrity management of subsea facilities. At the same time, it will be important to continuously follow-up the technology development, work processes, and collaboration to ensure safe and robust implementation of the concepts.

Future work should focus on:

- Gathering experiences from ROV pilots to further explore how non-conventional ROV-IMR concepts affect operations and data collection for integrity assessment from an operational perspective using an MTO perspective.
- Mapping emerging technologies (e.g., virtual and augmented reality, artificial intelligence, and autonomy) and their potential impact on integrity assessment.
- Evaluating the effectiveness and limitations of various inspection methods used in ROV-IMR operations.
- Evaluating advantages and disadvantages of traditional PDF-document-based reports and new reporting formats for inspection results and the implications for integrity assessment.

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1 Introduction

1.1 Problem statement and project objectives

The Norwegian Ocean Industry Authority (Havtil) observes an increasing use of IMR operations (Inspection, Maintenance, and Repair) carried out with Remotely Operated Vehicles (ROVs) controlled from shore-based control rooms (Remote Operation Centres – ROC). The purpose of this study is to map and shed light on current practices and future development trends related to non-conventional ROV-IMR operations. Havtil seeks to examine the extent of inspections and operations currently conducted from ROC, as well as planned measures and strategies for the further use of ROCs. Furthermore, the study shall identify the advantages, disadvantages, and risks associated with ROC operations compared with ROV-IMR operations conducted from IMR vessels (conventional ROV-IMR operations). Risk here relates to the potential consequences for the asset integrity of subsea facilities, which may result in leaks and failures with the potential for major accidents.

The findings of the study shall support Havtil's work with risk-based follow-up of ocean-based industry, particularly in relation to Chapter IX of the Activities Regulations on maintenance [1] – in particular § 50 Special requirements for technical condition monitoring of structures, maritime systems and pipeline systems [2] – and the Management Regulations Chapter II on risk management [3].

Background for the study is Havtil's work with continuous improvement of risk-based follow-up of activities, where the asset integrity of subsea facilities is a central focus area. Early audits related to ROV-IMR operations have unveiled deviations and areas for improvement. These are particularly related to follow-up of suppliers (see-to-it duty) within the regulatory frameworks for safety management [4], [5], and work environment and ergonomical design [6]. The study shall contribute to Havtil's work through six main contributions:

1. Description of different ROV-IMR concepts, including associated services (e.g., inspection, intervention), maintenance management of the ROVs and sensor equipment, as well as identification of strengths and weaknesses.
2. Mapping of the extent and experiences with different ROV-IMR concepts, both on the Norwegian Continental Shelf and internationally.
3. Mapping of the strategies and plans of the oil and gas companies and their suppliers regarding the development of different ROV-IMR concepts within the oil and gas industry.
4. Description of factors influencing the outcomes of IMR operations, including technical, human, and organizational aspects with both positive and negative impacts.
5. Description of changes in workflows and collaboration between oil and gas companies and other stakeholders, as well as consequences for situational awareness and integrity assessments.
6. Assessment of the consequences (both positive and negative) of employing non-conventional ROV-IMR concepts, including their impact on integrity assessments and on the overall integrity of subsea facilities.

1.2 Scope and limitations

The main focus of the study is on IMR operations, integrity assessments, and associated data collection using ROVs. The study shall evaluate whether the use of non-conventional ROVs may affect the integrity condition of subsea facilities, including pipelines, subsea templates, valves, X-mas trees, compressors, load-bearing structures, and associated subsea components.

Operations that are not considered to be part of IMR operations, including installation of subsea facilities, seafloor mapping, decommissioning and other similar activities, are not included in this study.

There are differences in the execution of inspection activities and other IMR tasks on pipelines and subsea cables compared to other types of subsea facilities. Inspections of pipelines and subsea cables are often carried out using smaller vessels (survey vessels), and the inspection results are typically available only after the completion of an inspection campaign.

Autonomous underwater vehicles and similar systems will not be addressed unless they carry out tasks that conventional ROVs have been carrying out previously.

1.3 Structure of the report

Chapter 2 summarises central terms and definitions, which builds the foundation for this report. Chapter 3 describes the methodology used. Chapter 4 provides the main contribution no. 1 by describing different ROV-IMR concepts (conventional and non-conventional) and relevant technological development particularities. Chapter 5 describes the main contributions no. 2 and no. 3, through summarising today's use of non-conventional ROV-IMR concepts, and through describing further plans and strategies to further develop and use such concepts. Chapter 6 evaluates the collected information and provides the main contributions no. 4, no. 5, and no. 6.

1.4 Abbreviations

AID	-	Autonomous Inspection Drone
AUV	-	Autonomous Underwater Vehicle
CP	-	Cathodic Protection
CRIOP	-	Crisis Intervention and Operability Analysis
CSWIP	-	Certification Scheme for Personnel
CTD	-	Conductivity, Depth and Temperature
FPROV	-	Fall Pipe ROV
FPSO	-	Floating Production Storage and Offloading
Havtil	-	Norwegian Ocean Industry Authority (Havindustritilsynet)
HOP	-	Human and Organisational Performance
IMCA	-	International Maritime Contractors Association
IMR	-	Inspection, Maintenance and Repair
LARS	-	Launch And Recovery System
MTO	-	Man-Technology-Organisation
OIM	-	Offshore Installation Manager
ROC	-	Remote Operation Centre, here understood as shore-based control room
ROV	-	Remotely Operated Vehicle
R-ROV	-	Resident ROV
SDS	-	Subsea Docking Station
TMS	-	Tether Management System
UID	-	Underwater Intervention Drone
USV	-	Unmanned Surface Vessel
UVMS	-	Underwater Vehicle Manipulator System

2 Background

This chapter summarises central concepts and background information, which forms the basis for this study. The central concepts and background information includes:

- Integrity assessment and management
- Remotely Operated Vehicles (ROVs)
- ROV-IMR operations
- Stakeholders and cooperation within ROV-IMR operations
- Man-Technology-Organisation-perspective
- Relevant regulations and standards

2.1 Integrity assessment and management

System integrity with respect to subsea facilities is understood as "*both the containment of fluids, and the reliable operation of safety- and production-equipment (valves, etc.). The objective is to ensure the safety and function of the [facility]*" [7]. The purpose of integrity management is to ensure that the integrity of the facility is maintained throughout the entire operational phase [8]. This entails that:

- Required safety margins are kept.
- Functionality of critical components is maintained.
- Robustness against relevant loads fulfil predefined acceptable criteria.

A generic integrity management cycle, as depicted in Figure 2.1, is iterated regularly as part of systematic integrity follow-up. Based on risk assessment and the maintenance program, an inspection campaign is planned that takes into account threats to system integrity, parameters influencing degradation mechanisms, as well as the condition assessed in earlier iterations of the management cycle (Step 1). Threats are understood broadly and may be both intentional and unintentional. Examples include corrosion (internal and external), erosion, cracking, fatigue, operational loads, temperature, pressure, damage, deformation, marine growth, foreign objects, quality deviations, and facility-related factors [8], [9]. The risk assessment considers equipment criticality, previous inspection campaigns, and experiences from comparable facilities collected over time. Thus, the subsea facility's history, including prior findings and interventions, is utilized in Step 1. Risk assessment and risk-based maintenance are embedded in Havtil's regulations, cf. Chapter 2.6.1.

Step 2 consists of the actual inspection of the subsea facility with the purpose of collecting data. In order to carry out data acquisition for the integrity assessment, the surface often needs to be prepared for inspection, either by flushing or by mechanical cleaning. The most common inspection methods are summarized in Section 2.3.1. Following the data collection, the integrity of the subsea facility is evaluated (Step 3). If the need for corrective actions is identified, interventions are carried out, these are described in Section 2.3.2. The results from Step 3, together with any interventions made in Step 4, form the basis for the next iteration of the integrity management cycle.

Figure 2.1: Generic integrity management cycle based on [7].

2.2 Remotely operated vehicle (ROV)

Remotely Operated Vehicles (ROVs), are defined in the industry standard NORSOK U-102 [10] as:

> "*An unmanned, underwater vehicle that is controlled from the surface by a pilot via a cable and is, in itself, a collection of equipment used in water with an ability to observe the surroundings and, in certain circumstances, intervene/interact with underwater infrastructure*."

Furthermore an ROV system is defined as [10] a "*System which comprises of the ROV […], the handling system, the surface control system and all associated equipment*."

An ROV is typically controlled by an ROV pilot using a joystick. ROVs may be equipped with one or more manipulator arms to perform intervention tasks and are employed in a wide range of operations, such as inspection, installation and maintenance of subsea equipment. Control signals and data are transmitted through a cable, commonly referred to as an umbilical, cable or tether, terms that are used interchangeably in practice. In this report, the term *umbilical* is used as the primary designation.

ROVs can be categorized in different ways [10], [11]. NORSOK U-102 [10] uses the categorisation shown in Table 2.1. The different ROV categories overlap to a certain degree. For example both NORSOK U-102 [10] and Capocci et al. [11] differentiate between **inspection-class ROVs** and **intervention-class ROVs**. According to Capocci et al. [11] intervention-class ROVs can be further categorized into two sub-categories (comparable to Class III in NORSOK U-102 [10]):

- **Light work-class:** Weigh typically between 100-1500 kg, is often fully electrical (except the hydraulic system for the manipulator arms), and can operate up to 3000 m depth. Are used for cleaning, inspection, as well as connection and disconnection of equipment.
- **Heavy work-class:** Weigh up to 5000 kg, are equipped with a hydraulic actuation system and can operate up to 6000 m depth. Mainly used for drilling and construction tasks.

Inspection-class ROV can be categorised as follows [11], which corresponds to *Class I* and *Class II* in NORSOK U- 102 [10]):

- **Micro/handheld**: Weigh between 3-20 kg, almost exclusively used for inspection tasks and can be deployed by hand.
- **Medium**: Weigh between 30-120 kg and can additionally carry out simple intervention tasks.

Intervention-class ROVs and medium inspection-class ROVs are often equipped with dedicated Launch and Recovery System (LARS), as well as Tether Management System, TMS. The LARS enables the safe deployment and retrieval of the ROV, while the TMS ensures controlled handling of the umbilical during operations. To perform specialized tasks, ROVs may be fitted with a skid – a modular frame that is mounted on the ROV or deployed separately. The skid may contain hydraulic units, flushing tools, sensors, or other specialized equipment.

Table 2.1: Classification of ROVs according to NORSOK U-102 [10].

Category	Description
Class I	Pure observation
Class II	Observation with payload option
Class II A	Observation-class vehicle with payload option
Class II B	Observation-class vehicle with light intervention, survey and construction capabilities
Class III	Work-class vehicles
Class III A	Standard Work-Class Vehicle
Class III B	Advanced Work-Class Vehicle
Class IV	Towed and Bottom Crawling vehicle
Class IV A	Towed Vehicles
Class IV B	Bottom Crawling Vehicles
Class V	Prototype or development vehicles
Class VI	Autonomous Underwater Vehicles (AUV)
Class VI A	AUVs Weighing < 100 kg
Class VI B	AUVs Weighing > 100 kg
Class VII	High speed survey vehicles
Class VIII	Fall pipe ROV (FPROV)

Autonomous Underwater Vehicles (AUVs) describe unmanned underwater vehicles that operate autonomously over a longer period of time. AUVs are used traditionally for pipeline inspections and mapping of the seafloor. They are normally shaped more hydrodynamically than ROVs.

As technology has advanced, the distinction between ROVs and AUVs has become less clear, for example in the technology development projects [12], [13], [14]. This has led to new hybrid forms and associated terminology, among others:

- **UID** – Underwater Intervention Drone
- **AID** – Autonomous Inspection Drone
- **UVMS** – Underwater Vehicle Manipulator System
- **RROV** – Resident ROV

2.3 ROV-IMR operations

ROV-IMR operations can be either inspections or interventions:

- **Inspections** involve observing and collecting data on the condition of a structure or component, with the purpose of detecting damages, wear, marine growth, cracks, corrosion, and similar conditions. This also entails preparation and cleaning of surfaces for inspection.
- **Interventions**, on the other hand, entail performing an active action that affects or modifies a structure, for example by repairing, adjusting, replacing, or operating equipment on the structure.

The distinction between inspection and intervention is, however, not always clear-cut. For example, during visual inspection it may be necessary to remove marine growth to enable condition assessment, an activity that represents a form of intervention. The DNV standards [8], [15] provide a comprehensive overview of task types and associated technologies, and serve as reference in the development and evaluation of non-conventional IMR concepts.

2.3.1 Inspection methods

Different inspection methods are in use [8], [16], [17], which can be categorised as follows:

- **Visual inspection using cameras**: Used to detect corrosion, cracks, and mechanical damage (e.g., on jackets, platform legs, risers, and equipment in the water column), as well as to evaluate the condition of surface coatings. The images may also be used for photogrammetry and 3D modelling.
- **Hydroacoustic and sonar-based inspection** (multibeam, etc.): Used, among others, for inspecting pipeline position and free spans, as well as for mapping seabed topography and sediment displacement.
- **Stabbing**: Used to measure specific properties of a structure or component with a sensor or probe that is physically pressed against or into the object. This is therefore a contact-based inspection method. Examples include the use of a CP probe (cathodic protection) to indicate the level of cathodic protection or stabbing of anodes to verify that they are not porous or degraded.
- **Electromagnetic and ultrasonic inspection**: Used to detect cracks, corrosion, and defects in materials and welds, as well as to measure wall thickness and identify structural damage.
- **Flooded member detection**: Used to detect water ingress in structural elements.
- **Pipe tracker**: Used to locate pipelines beneath the seabed and assess potential positional changes.
- **Laser-based inspection**: Similar to hydroacoustic and sonar-based inspection methods, utilizing laser light. It requires closer proximity to the object. Well suited for high-resolution 3D modelling and precise position measurements of subsea structures.
- **Specialised chemical sensors**: Used to detect hydrocarbons or other chemicals in the water.
- **Conductivity, Depth and Temperature (CTD) probe**: Used to measure environmental parameters such as pressure, salinity, and temperature.

A distinction can be made between contactless inspection methods, which utilize, for example, cameras or sonar, and contact-based inspection methods, which, as the term implies, require physical contact with the structure being inspected.

2.3.2 Intervention

Interventions are used as part of preventive maintenance, for example:

- Cleaning and flushing.
- Testing valves and other components.
- Calibrating and adjusting sensors and instruments.

Preventive maintenance activities also include both contactless and contact-based inspection methods, as described in the previous section. In addition, interventions are used for corrective maintenance action, such as:

- Repair.
- Replacing defective parts.
- Welding and sealing holes.
- Removing sediment and other unwanted material.
- Hot stabbing: connecting or disconnecting hydraulic or electrical tools and systems while they are pressurized and in operation.

2.4 Stakeholders and cooperation within integrity management and ROV-IMR operations

Several stakeholders are involved in the planning and execution of ROV-IMR operations. In addition, various stakeholders contribute to the integrity assessment process. The actors associated with ROV-IMR operations may belong to the same oil and gas company, but in many cases service providers perform one or more tasks.

This summary has been prepared based on the interviews with the industry (cf. Section 3.2). Minor variations may occur between oil and gas companies regarding terminology and organisation, depending on the company's size and the types of facilities it operates. The steps mentioned refer to the integrity assessment cycle shown in Figure 2.1.

Some companies operate their own ROVs with associated personnel and equipment. As a simplification, this report assumes that ROV-IMR operations are carried out solely by service providers. These service providers can broadly be divided into two groups:

- Service providers responsible for integrity assessment and management.
- Service providers responsible for conducting the IMR operations.

Figure 2.2 summarizes the current stakeholder landscape, indicating interactions and location. Potential changes in the stakeholder landscape and collaboration arising from the use of non-conventional ROV-IMR operations are discussed in Section 6.2.

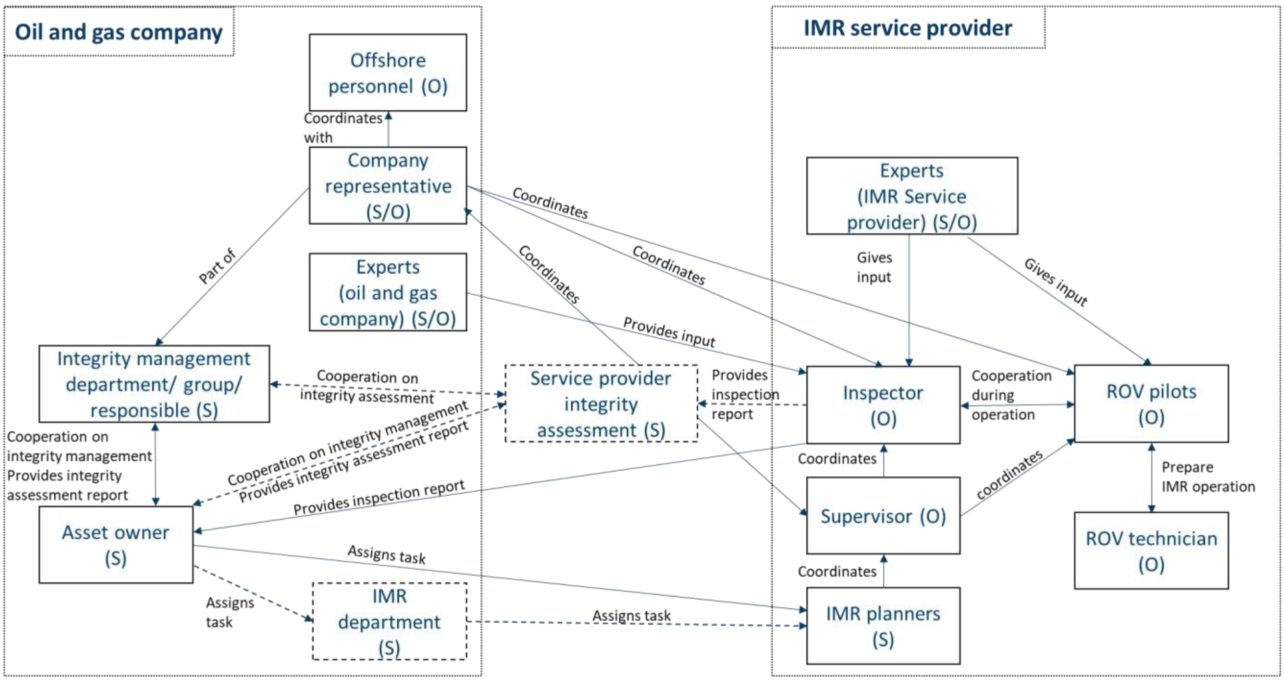

Figure 2.2: Overview of stakeholders within ROV-IMR operations and integrity assessment. Broken lines indicate that there are large variations regarding the involvement of this type of stakeholder. (S) indicates that the stakeholder is located on shore, and (O) that the stakeholder is located offshore. In the case of (S/O), the stakeholder may be on shore or offshore.

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2.4.1 Relevant stakeholders within the oil and gas companies

The **asset owner** is responsible for ensuring that the subsea facility complies with requirements and is operated at an acceptable level of risk. The asset owner is responsible for initiating necessary ROV-IMR operations to assess the condition of the subsea facility (Step 1) and, if required, restore it (Step 3). In many cases, there are different asset owners for pipelines, subsea structures, and subsea control systems.

The integrity management department/group/responsible supports the asset owner in carrying out the tasks (Step 1 and Step 3) and in following-up the subsea facility. Depending on the company's size, this may be organized as a dedicated department, a group, or an individual role. This includes, among other things, identifying inspection needs, planning of ROV-IMR operations and campaigns, as well as reporting. In some cases, other disciplines and subject matter experts may also be involved, such as geologists, subsea control system engineers, and other relevant disciplines.

An **IMR department** or IMR group exists in some companies as a separate unit, with responsibility for coordinating the company's IMR needs with both in-house and contracted vessels from service providers. They receive requests for ROV-IMR operations and subsequently plan campaigns in collaboration with subject matter experts and the system owner. They are therefore involved in Steps 1 through 4.

The **company representative** is present during the ROV-IMR operation (Steps 2 and 4) and serves as a liaison between the IMR service provider and other stakeholders, such as offshore personnel on the offshore facility and other vessels in the area. In addition, the company representative monitors the operation and provides input and answers to the supervisor, ROV pilots, and inspector as needed. The company representative is located either on board the IMR vessel (particularly during operations within the 500-meter safety zone) or onshore.

Offshore personnel such as the Offshore Installation Manager (OIM), control room operators, crane operators, the captain and crew of the IMR vessel, and the captain of a diving support vessel or an emergency preparedness vessel may be involved in ROV-IMR operations (Steps 2 and 4) in various ways through the company representative, particularly during ROV-IMR operations within the 500-meter safety zone.

The OIM is responsible for the facility and must therefore approve work on the subsea facility. Control room operators must be aware of the operation through the permit-to-work system. The IMR vessel's captain and crane operators contribute to the efficient handling of ROVs. Other vessels, such as diving support vessels or emergency preparedness vessel associated with the facility, may require coordination during ROV-IMR operations.

Experts (oil and gas company) are called in when needed, for example geologists, materials engineers, or other discipline specialists. Their presence is often required only for a limited period during ROV-IMR operations (Steps 2 and 4).

2.4.2 Service provider integrity assessment

The service provider integrity assessment supports the oil and gas company in integrity management by carrying out certain tasks or assisting in their execution. Examples of such tasks include risk assessments, support in the development of maintenance programs, planning of the IMR program for the upcoming period (Step 1), as well as performing integrity assessments based on collected data (Step 3). Integrity assessment and the preparation of the integrity report are carried out in close collaboration with the oil and gas company. The company's size and the types of facilities it operates determine the scope and level of involvement of this type of service provider.

2.4.3 IMR service providers

IMR service providers carry out the ROV-IMR operations. They own the vessel, ROVs and provide the necessary crew. In some cases, the IMR service provider is closely linked to the ROV system supplier, e.g., when both belong to the same corporate group. As a result, IMR service providers may test non-conventional ROV-IMR concepts in collaboration with oil and gas companies.

IMR vessels typically have between two and three ROVs on board. Survey vessels and smaller vessels usually carry one or two ROVs. The size and equipment of the IMR vessel determine how many ROV-IMR operations can be conducted simultaneously.

IMR planners receive requests for IMR services and plan the ROV-IMR operations in collaboration with the asset owner and the IMR department (Steps 1, 2, and 4). The planning process includes defining the approach, methods, and tools to be used, as well as estimating the duration of the operation.

An ROV is usually operated by two **ROV pilots** during an ROV-IMR operation (Steps 2 and 4). One pilot controls the ROV's manipulators, for example to prepare surfaces for inspection, perform hot stabbing, operate valves, and similar tasks. The second pilot controls the ROV itself and ensures that the umbilical does not become entangled with the subsea facility. In certain operations, the second pilot may also operate the ROV's second arm.

The **inspector** is responsible for collecting the data used in the integrity assessment (Steps 2 and 3). The inspector guides the ROV pilots to the relevant inspection sites and points of interest and is located in the same control room as the ROV pilots. To perform this role, the inspector must have thorough knowledge of the subsea facility and the specific threats applicable to the facility. Inspectors are usually certified in accordance with CSWIP-DIV-7-95 Part 2 [18]. For less complex inspections, an ROV pilot may assume the role of inspector.

The **ROV technician** is responsible for preparing tools on the ROV and for maintaining the ROV between operations (Steps 2 and 4). Different tools are used to carry out various ROV operations, e.g., operating valves, performing hot-stabbing, or preparing surfaces for inspection. Maintenance tasks include cleaning the ROV after operations, cleaning, calibrating and replacing sensors, refilling hydraulic oil, replacing worn parts, performing repairs, etc. In many cases, ROV pilots may also assume the role of ROV technician.

The **supervisor** coordinates and supports the different ROV crews (Steps 2 and 4). Commonly, two ROVs are used simultaneously. The supervisor acts as a link between the crews and closely monitors the operations to ensure that no conflicts or issues arise, such as the umbilicals becoming entangled.

Experts (IMR service provider) are called in when needed, for example geologists, materials engineers, or other specialists. During ROV-IMR operations (Steps 2 and 4), their presence is often required only for a limited period.

2.5 MTO (Man-Technology-Organisation) and Human Factors

Man-Technology-Organisation (MTO) is a systems perspective that is based on the understanding that different factors within a system may interact in complex ways and therefore must be analysed holistically [18]. The MTO approach is used to analyse the interaction between human, technical, and organizational factors. A common challenge in applying the MTO perspective is that the individual elements (M, T, and O) are analysed in isolation, in so-called silo analyses, without sufficient focus on their interaction. A holistic analysis grasping the system as a whole requires insight into all three areas, as well as an understanding of how factors within them influence each other.

The MTO approach is particularly relevant for ROV-IMR operations, as it encompasses both collaboration across different organizations and the application of new technology and non-conventional ways of working. A holistic systems perspective is therefore essential.

Human Factors is the discipline that examines human performance in interaction with technical and organizational factors in the development and operation of systems. Fundamental to Human Factors is the identification and understanding of conditions that affect human performance [19]. This includes, among other things:

- Factors related to the work itself (e.g., available time and the design of control panels).
- Personnel-related factors (e.g., workload and capacity).
- Organizational factors (e.g., roles and staffing).

The concept of Human and Organisational Performance (HOP) has increasingly gained interest among Norwegian oil and gas companies. HOP represents a management philosophy aimed at strengthening leaders' understanding of the operational needs of personnel. This is intended to support learning and the development of safety practices, while at the same time enhancing the robustness of operations [20].

2.6 Regulations and standards

Norwegian regulations and standards that are relevant for ROV-IMR operations are listed below. They will be shortly described in the following paragraphs.

- Oil and gas regulations:
    - Activities regulations (Aktivitetsforskriften)
    - Management regulations (Styringsforskriften)
- NORSOK U-102:2020 Remotely operated vehicle (ROV) services
- DNV recommended practices:
    - DNV RP-F116 Integrity Management of Submarine Pipeline Systems
    - DNV RP-0002 Integrity Management of Subsea Systems
- Other standards
    - CSWIP-DIV-7-95-Part 2
    - International Maritime Contractors Association (IMCA) provides relevant standards that are not accessible without a membership. These are not included in this study.

2.6.1 Regulations for the oil and gas industry

According to Havtil, their follow-up of ROV-IMR operations is primarily founded in the following parts of the oil and gas regulations:

- **Activities regulations Chapter IX** Maintenance [1].
- **Activities regulations § 50** Special requirements for technical condition monitoring of structures, maritime systems and pipeline systems [2].
- **Management regulations Chapter II** Risk management [3].

The regulatory requirements are formulated as functional requirements and do not differentiate between activities performed above or below water. [1] This means that lower quality requirements are not permitted for inspection, maintenance, risk management, etc. subsea. Consequently, the regulations also do not explicitly address non-conventional ROV-IMR concepts. The guidelines to the regulations, however, make several references to recognized standards that may be applied to meet the required safety level. The regulations themselves, however, do not directly reference any of the standards considered most relevant for ROV-IMR operations.

Havtil's regulations nevertheless mention several thematic areas and key terms that form the basis for the literature review and interviews with the industry related to the study's research questions (cf. Chapter 3). Examples of such areas include planning, risk assessment, safety measures, emergency preparedness, competence, training, inspection, instrumentation, aging, and more.

2.6.2 NORSOK U-102 Remotely operated vehicle (ROV) services

The industry standard NORSOK U-102 [10] establishes technical, operational, and administrative requirements for ROV operations, as well as competence requirements for personnel. Furthermore, the standard provides a classification of ROVs into eight main categories with associated subcategories, as shown in Table 2.1 above. The ROV categories reflect to some extent an increasing complexity in technology and operations.

Control from shore is briefly addressed in the standard, where the following points are of most interest:

- The shore-based control room (ROC) shall be fully capable of controlling the ROV.
- Robust routines should be established for communication between shore and offshore personnel.
- Procedures must be in place to handle communication loss and emergency preparedness.

2.6.3 DNV Recommended Practices

Two central DNV Standards are related to integrity management subsea:

- **DNV-RP-0002**: *Integrity management of subsea production systems* (2019/2021) [8].
- **DNV-RP-F116**: *Integrity management of submarine pipeline systems* (2021) [15].

Both standards highlight ROVs as a recommended and essential tool for subsea integrity management, with particular emphasis on inspection. The actual operation of ROVs is not addressed in the standards, and control from shore is therefore not mentioned. Roles and collaboration are likewise not covered in the standards. Nevertheless, the DNV standards provide a good overview of task types and technologies, which form part of the basis for the literature review and the interviews with the industry (cf. Chapter 3).

2.6.4 Certification Scheme for Personnel (CSWIP)

CSWIP-DIV-7-95-Part 2 [21] forms the basis for the certification of ROV inspectors. It is intended to ensure that inspectors meet a defined minimum requirement with respect to skills and knowledge related to inspection methods, inspection techniques, recording equipment, inspection planning, and understanding of the operations they are to perform. The standard defines two certification levels, 3.3U and 3.4U, where 3.4U builds on 3.3U and requires more knowledge and experience, particularly regarding diving operations. Requirements include medical fitness, relevant work experience, training courses, and passing both a written and practical examination. The issued certificates are valid for five years.

[1] When "underwater" is mentioned, is this always with respect to manned operations (diving).

3 Methodology

The information required for this study is dispersed across multiple sources. A document review forms the basis for both the interviews with the industry and the description of various ROV concepts. The companies themselves hold a substantial amount of information, including experiences related to the strengths and weaknesses of non-conventional ROV concepts, and visions and strategies for the future. This information has been gathered through semi-structured interviews. The interviews complement the findings from the document review, cf. Figure 3.1. The assessment of ROV concepts and potential changes in the workflow has been carried out at a high level, based on the collected information.

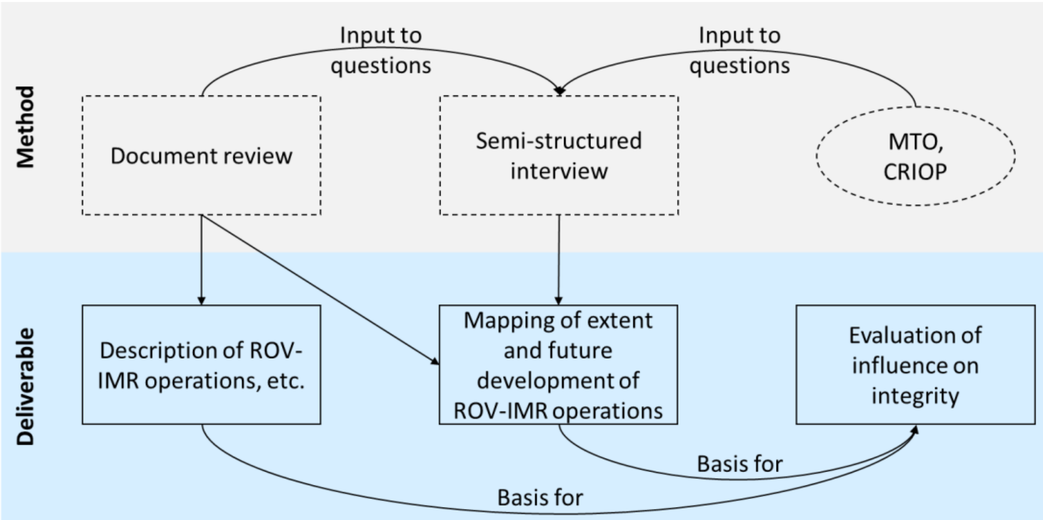


Figure 3.1: Methodological approach to the study.

3.1 Document review

The document review is based on national and international projects, technical reports, documents from Havtil and relevant organizations, as well as academic literature. The literature search was conducted in the OnePetro database[2], which is the oil and gas industry's technical literature database. The following keywords were used in the search:

- IMR, Inspection Maintenance Repair, Intervention
- Integrity assessment, Asset Integrity
- ROV, Remotely Operated Vehicle, Underwater Vehicle, Underwater Robot
- Challenges, Risk, Safety, Human factors, Innovation
- Remote Operation Center, Resident, Garage

All identified documents were assessed for relevance. Documents addressing non-conventional ROV-IMR concepts, their development, adoption, weaknesses, strengths, factors influencing the operations, and how such changes affect situational awareness and the outcomes of ROV-IMR operations were considered relevant. In addition, documents describing integrity assessment of subsea facilities, as well as technical, human, and organizational factors related to ROV-IMR operations, and operational experiences from different ROV systems, were selected.

Relevant documents were used in the descriptions and assessments throughout the report to provide the most comprehensive picture possible.

[2] https://onepetro.org/.

3.2 Interviews with the industry

Interviews were conducted with industry stakeholders, including oil and gas companies, service providers, and system suppliers. The interviews were held in a conversational style and were carried out in a semi-structured interview format [22], in which the informants responded to open-ended questions related to selected main themes described in an interview guide. This conversational format was chosen over formal interviews to facilitate an open and constructive dialogue. When necessary, predefined follow-up questions were used to obtain additional information. The interview guide was developed based on background information from the document review and relevant methods such as the CRIOP analysis (Crisis Intervention and Operability) [23] and the MTO perspective. Havtil provided input on the design of the interview guide.

The interviews were conducted digitally and lasted approximately 1–1.5 hours. One representative from SINTEF led the conversation, supported by a presentation that included the questions and relevant background information. Two people took notes during the session. Both the interview guide and the presentation were sent to the companies in advance, enabling them to select relevant participants and prepare answers. After each conversation, the notes were sent to the companies to ensure the accuracy of the information recorded. When distributing the notes, SINTEF asked a few short follow-up questions if necessary.

The companies invited to participate in the interviews were selected in collaboration with Havtil. In total, nine interviews were conducted. The companies themselves could decide who would participate. In total, 24 participants took part, representing IMR department managers, subsea system specialists, discipline engineers, system developers, regulatory affairs representatives, project managers, project engineers, and ROV pilots. The conversations were planned to be conducted in Norwegian, although some companies preferred to conduct them in English. The following companies participated in the conversations:

- Oil and gas companies:
  - Aker BP
  - Equinor
  - Norske Shell
  - Gassco
  - Vår Energi
- IMR service providers and system suppliers
  - Oceaneering
  - IKM
  - Saipem Norway (Sonsub)
  - Reach Subsea

A simple qualitative analysis was conducted to extract relevant information on the extent of operations, the development of non-conventional ROV-IMR concepts, plans, strategies, and factors influencing integrity assessment. Thematic analysis was used to group the information into codes, a method used to identify, analyse, and describe patterns in a dataset [24]. Due to the limited number of conversations, it was not possible to perform a statistical analysis.

3.3 Evaluation and comparison of ROV-IMR operational concepts

Non-conventional ROV-IMR concepts are qualitatively assessed against and compared with conventional ROV-IMR operations. The criteria for the assessment are based on the purpose of the study, namely, to highlight how the use of non-conventional ROV-IMR concepts may influence integrity assessment. In addition, the criteria have been further developed and specified based on input from the interviews, where stakeholders emphasized factors, they consider particularly important. The assessment provides the basis for the subsequent recommendations and conclusions of this study.

4 ROV-IMR concepts and technological development

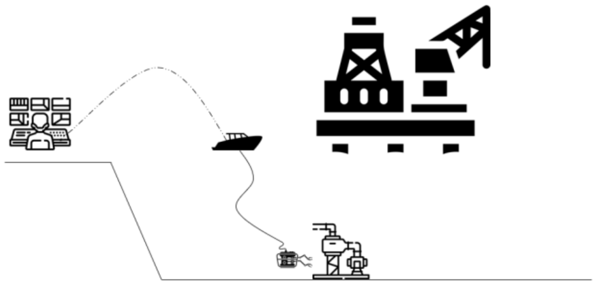
This chapter describes ROV-IMR concepts currently in use, as well as concepts under development and testing. The chapter draws on examples of concepts that are publicly available online. Other companies may have similar concepts that are not mentioned here, this does not imply that these are less relevant or of lower quality. The information forming the basis for the descriptions has been obtained from the document review, for example Dalhatu et al. [25], [26], the Offshore Magazine's special report [27], the Safesub project [13], and from the information gathered through the interviews.

In Dalhatu et al. [13] new ROV operational concepts are categorised as follows:

- **Deployment concept:** Describes how the ROV is deployed for operation. See Figure 4.1 for an overview of the deployment concepts described in this report.
- **Communication and charging concept:** Describes concepts for power transmission and data communication between the ROV and the control room. Wireless communication may be acoustic (low bandwidth, longer range) or optical (higher bandwidth, shorter range). Examples include:
    - Conventional operation, where the ROV receives power and communicates via an umbilical to the IMR vessel (and, if applicable, satellite communication between the ROC and the IMR vessel).
    - Communication and power supply from a subsea garage, where the garage either has an external, cabled power supply or is equipped with a larger battery and wireless communication (via a surface buoy) to the IMR vessel and/or the ROC.
    - Wireless subsea vehicles that recharge as needed in a dedicated charging infrastructure.
    - Hybrid solutions, where the subsea vehicle can switch between operating with and without an umbilical for charging and power supply.
- **Monitoring and control concept**: Encompasses different solutions for the control and monitoring of ROV operations. ROVs with an umbilical allow for continuous control and monitoring, whereas ROV operations without an umbilical require a higher degree of autonomy in the ROV, and thus more intermittent involvement from the control centre. Examples include:
    - ROC.
    - Mobile ROC, for example container based.
    - Control room on the IMR vessel.
    - Control room on an offshore facility.
    - A combination of the above.

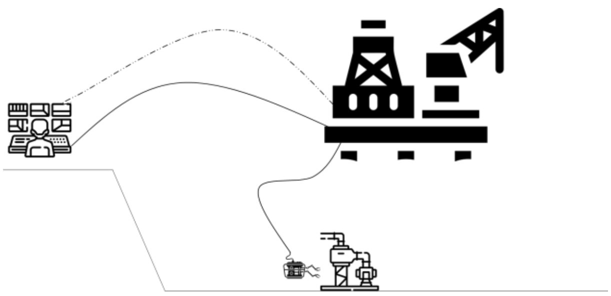
This report focuses on ROV-IMR operations from ROCs. Therefore, this monitoring and control concept is taken as basis for this report. The ROV-IMR concepts are subsequently categorized according to the type of deployment concept. The deployment concepts in Figure 4.1 have been developed mainly with a focus on ROV-IMR operations on subsea facilities with limited geographical scope. For other IMR tasks, for example involving inspection and monitoring of long linear infrastructure, such as pipelines, some of the concepts will still be relevant (C1, C3, and C5). When using concept C1 (conventional IMR vessel), umbilical-free inspection ROVs, i.e., an AUV, may also be employed.

C1. Conventional ROV-IMR operations from an IMR vessel.
ROVs are connect to the IMR vessel through an umbilical. ROV crew on board of the IMR vessel. Wireless communication to shore is also possible.

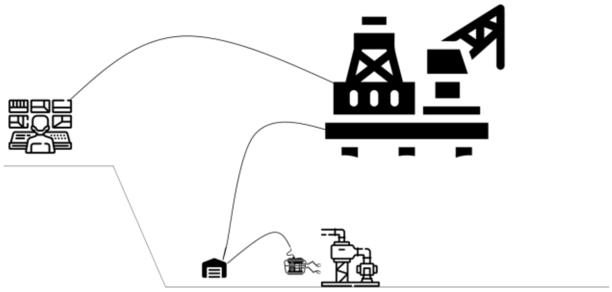


C2. ROV deployed from an unmanned vessel.

ROV s are connected to an unmanned vessel through an umbilical. Wireless communication to shore.

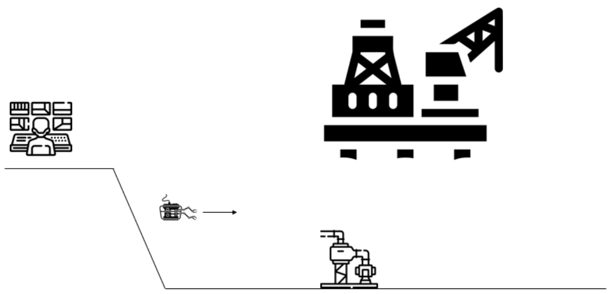


C3. ROV deployed from an offshore facility
ROVs controlled through an umbilical. Wired or wireless communication to shore.



C4. ROV with permanent subsea garage.
ROVs connected most often to the garage through an umbilical. Wired communication to shore.

C5. ROV with temporary subsea garage.
ROV umbilical to the communication buoy on the surface. Wireless communication to shore.



C6. ROV deployed from shore.
ROVs operated without communication to shore, except when on the surface or communication through the infrastructure on the seafloor.

Figure 4.1: Overview of ROV-IMR concepts (C1-C6). Broken lines indicate wireless communication, solid lines indicate data transfer through a cable, or umbilical, tether. All concepts could be umbilical free for a certain time. However, the use of an umbilical is the most common practice, except for C6 (ROV deployed from shore).

4.1 C1. Conventional ROV-IMR operations from an IMR vessel

The most widespread and thus “conventional” concept for ROV-IMR operations is that the ROV is deployed and controlled from a manned IMR vessel. An umbilical runs from the IMR vessel to the ROV, allowing for controlling and monitoring of the ROV operation. The ROV crew, inspector, and relevant members of the IMR vessel crew are located in the same control room and can coordinate closely during the preparation and execution of the ROV-IMR operation.

Even though a full crew is on board the IMR vessel to operate the ROVs, it is in some cases also possible to control and monitor ROV-IMR operations from a shore-based ROC. This allows for, among other things, the involvement of experts who are not offshore and may free up capacity on board the IMR vessel. However, data transfer via satellite or a mobile carrier between the IMR vessel and shore may reduce the quality of live video transmission (e.g., pixelation of the image), which in some cases may require that video and images are downloaded onshore after the operation.

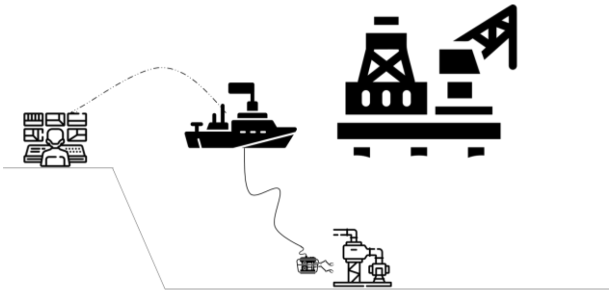


Figure 4.2: Concept sketch of conventional ROV-IMR operations from an IMR vessel.

ROV-IMR campaigns often involve multiple locations that lie beyond the reach of the ROV from a single position of the IMR vessel. In such cases, the ROV is recovered, and the IMR vessel is relocated to the next operational area.

Trials have also been conducted using an AID, an autonomous inspection-class ROV, in conjunction with operation of an intervention-class ROV from an IMR vessel. One example is the collaboration between Aker BP, DeepOcean, Remota, Argus Remote System, and Vaarst[3]. In this setup, the AID could be monitored and, if necessary, controlled from Remota’s operations centre onshore.

Some strengths (+) and weaknesses (-) with the concept are:

+ Comparably easy to move the ROVs between locations by recovering them and moving the IMR vessel to the next location.
+ Most operational roles in the ROV-IMR operation (diving support vessel or emergency preparedness vessel captain, ROV pilots, inspector, and supervisor) are physically co-located on board. Some interview participants report this as a strength, enabling more seamless and efficient communication during planning and handling of unforeseen events.
+ A technician is available on board and can, if needed, repair the ROV or exchange equipment.
– An IMR vessel near an offshore facility may increase the risk of a collision.
– IMR vessels for conventional ROV-IMR operations are comparably large and are associated with high operational cost and significant release of greenhouse gases.

[3] Offshore Magazine, 2024, Autonomous drone passes initial inspection trials at North Sea Alvheim Field, https://www.offshore-mag.com/business-briefs/equipment-engineering/article/14303700/deepocean-autonomous-drone-passes-initial-inspection-trials-at-north-sea-alvheim-field, accessed 30. May 2025.

4.2 C2. ROV deployed from an unmanned vessel

Concepts are being developed and tested for launching (and recovering) ROVs from unmanned surface vessels (USVs). The concepts range from the use of ROVs with an umbilical to subsea vehicles with intervention capabilities without an umbilical. The ROV is typically operated from an ROC, which may either be permanent or moveable, i.e., be relocated to where the USV docks. The ROV is prepared and maintained onshore before deployment with the USV, and after the USV returns. In some cases, tool changes and similar operations can also be performed automatically on board the USV.

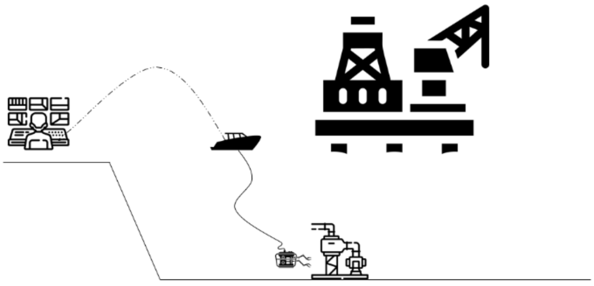


Figure 4.3: Concept sketch of ROV being deployed from a USV.

Figure 4.4: Reach Subsea and partners have developed a USV, which is used to launch ROVs. The picture is reproduced with permission by Reach Subsea.

An example of this concept category is the *Reach Remote 1* from Reach Subsea with partners. This involves a 24-meter USV with an intervention-class ROV on board, controlled and monitored from an ROC[4], see Figure 4.4.

Another example is the *Aquanaut*[5] from Nauticus Robotics, an umbilical-free subsea vehicle with intervention capabilities, which is deployed and recovered using a USV. Since *Aquanaut* is not connected by an umbilical, communication to and from the vehicle is more limited. Thus, operations must be carried out more autonomously, compared to more conventional solutions where ROVs are continuously controlled and monitored from an ROC.

The *Aquanaut* concept combined with a USV is considered to have a somewhat lower technology readiness level than *Reach Remote 1*. The evaluation of the *Aquanaut* concept and *Reach Remote 1* is based on the fact that the *Reach Remote 1* vessel was delivered in May 2025 and equipped with an ROV for a pilot project with, among others, Equinor and TotalEnergies[6]. Nauticus Robotics reported its second acceptance test with *Aquanaut* in a test basin in February 2025[7]. For the combination of *Aquanaut* and a USV, they announced future collaboration with the USV supplier Open Ocean Robotics [8].

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[4] Offshore Magazine, January 2025, Reach Subsea prepares first uncrewed vessels for multi-field North Sea surveys, https://www.offshore-mag.com/vessels/news/55263218/reach-subsea-prepares-first-uncrewed-vessels-for-multi-field-north-sea-surveys, visited 30. May2025.

[5] Nauticus Robotics, Product Sheet, "Aquanaut – the future of underwater robotics", https://nauticusrobotics.com/aquanaut/, visited 29. May 2025.

[6]Maritimt Magasin, May 2025, Reach Remote 1 2025-05, https://maritimt.com/reach-remote-1-2025-05, visited 13. June 2025.

[7] Offshore Energy, February 2025, US autonomous subsea robot enters acceptance testing phase, https://www.offshore-energy.biz/us-autonomous-subsea-robot-enters-acceptance-testing-phase/, visited 13. June 2025.

[8] Offshore Energy, June 2025, Nauticus Robotics and Open Ocean Robotics team up on subsea asset monitoring, https://www.offshore-energy.biz/nauticus-robotics-and-open-ocean-robotics-team-up-on-subsea-asset-monitoring/, visited 13. June 2025.

Some strengths (+) and weaknesses (-) with the concept are:

+ Allows for the transfer of ROVs between subsea facilities. This is similar to conventional ROV-IMR operations.
+ Can reduce operational cost and environmental footprint compared to using a (large) manned IMR vessel. In addition, a USV may be mobilized more easily and at shorter notice than an IMR vessel.
  – If an IMR vessel is already present in the area where an ROV is needed, and the operation could be performed when the vessel is anyway available, these advantages may be less significant.
– The ability to deploy an ROV depends on weather and sea conditions, particularly when smaller USVs are used.

4.3 C3. ROV deployed from an offshore facility

Some offshore facilities (oil platforms, Floating Production Storage and Offloading units (FPSOs)) may have one or more smaller ROVs (less than 30 kg) that can be deployed for inspection in the area around the facility and on infrastructure connected to it (e.g., risers). An ROV may also be deployed offshore with a temporary operations container and associated personnel. Then the ROV may be operated either from the facilities or from an ROC. The ROV is deployed using cranes on the facility or manually from the diving deck in the case of smaller ROVs.

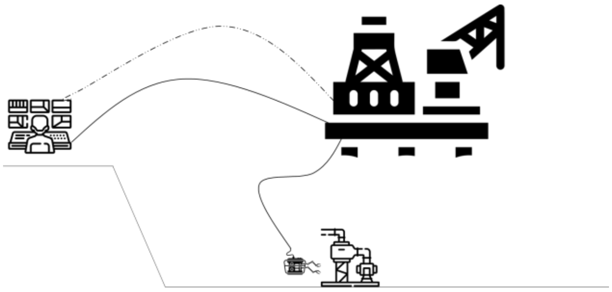


Figure 4.5: Concept sketch of ROV being deployed from an offshore facility.

Some strengths (+) and weaknesses (-) with the concept are:

+ The ROV can be deployed relatively quickly and used flexibly.
– ROV personnel must remain on the offshore facility.
– Operations containers used offshore may have poor indoor climate conditions.

4.4 C4. ROV with permanent subsea garage

The defining feature of this concept is that the ROV is stationed on the seafloor in the work area for an extended period, typically for several months between recoveries. The ROV is supported by dedicated infrastructure in the form of a *garage*, which is used for power supply and communication with control rooms onshore and offshore. The garage may also contain various tools that the ROV can collect and use during operations. ROVs operating from such garages are often referred to as resident ROVs, or *permanently stationed* ROVs. In this report, the term *permanent garage* is used, even though both the garage and the ROV must in practice be retrieved regularly for maintenance.

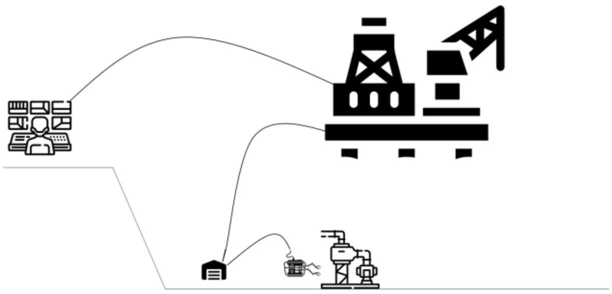


Figure 4.6: Concept sketch of ROV with permanent subsea garage.

Permanent garages allow for cabled communication between the ROV offshore and the ROC. The world's first commercial shore-controlled operation with an intervention-class ROV was carried out by IKM Subsea (R-ROV) in 2017 at Equinor's Snorre B field[9]. The ROV was equipped with a dedicated garage. The industry is working to extend the intervals between required maintenance.

There are different types of ROVs with permanent garages. Some are always connected to an umbilical (e.g., the *R-ROV* by IKM), others are designed to operate both with and without an umbilical (e.g., the *Hydrone-R* by Saipem[10] and the *Sabertooth* by Saab[11]). Some ROVs operate mainly without an umbilical. When an ROV can travel greater distances without an umbilical, this enables the ROV to move autonomously between subsea facilities. In such cases, garages may be required at each facility. A cost-benefit assessment must be conducted to determine whether such infrastructure is feasible. To our knowledge, concepts where ROVs can move between subsea facilities and garages have not yet been significantly operationalized. Such solutions are likely to be most suitable for fields with multiple subsea facilities distributed within a relatively small area.

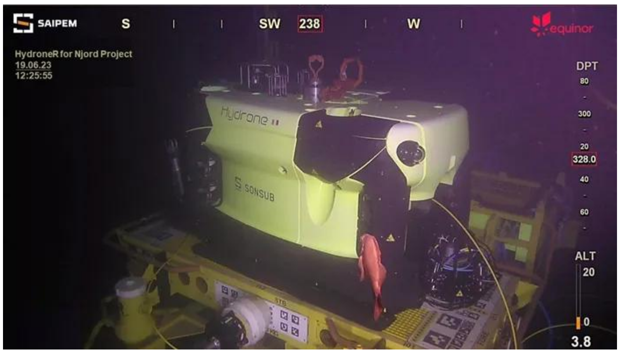
There are different types of garages. Some are specifically designed for a particular type of ROV and have an integrated TMS for the ROV. An example is the *R-ROV* system by IKM, which is stationed at Equinor's Snorre B field (see Figure 4.7(a)). Other types of garages are built to be used by multiple types of subsea vehicles but generally have more limited functionality and equipment. An example of this is the *Subsea Docking Station* (SDS) by BlueLogic (see Figure 4.7(b)), which primarily functions as a charging pad. Various ROVs and other subsea vehicles have been adapted to recharge at such docking stations, including the *Freedom AUV* by Oceaneering and the *M-series* by Eelume[12]. The combination of the SDS and the *Hydrone-R* by Saipem, makes it possible to connect an umbilical, allowing the *Hydrone-R* to be remotely operated by a pilot. In 2024, Saipem reported continuous subsea deployment of its *Hydrone-R* at Equinor's Njord field for 167 days.

Some strengths (+) and weaknesses (-) with the concept are:

+ "Always" available. Not dependent on, for example, a weather window and no delays caused by the time required to mobilize an IMR vessel to the area for ROV deployment. If an IMR vessel is already in the area where the ROV is needed, the difference in response time will be smaller.
+ May reduce operating costs and environmental footprint compared to the use of a (large) manned IMR vessel.
– With current concepts and the available subsea infrastructure, operations are generally limited to a single subsea facility.

[9] Offshore Engineer, 2017, Milestone in remote ROV control achieved in Norway, https://www.oedigital.com/news/446329-milestone-in-remote-rov-control-achieved-in-norway, visited 30. May 2025.
[10] Saipem, The new technological frontier for subsea operations, https://www.saipem.com/en/solutions-energy-transition/robotic-solution, visited 30. May 2025.
[11] Saab, Sabertooth, https://www.saab.com/products/sabertooth, visited 30. May 2025.
[12] Eelume, M-series, https://www.eelume.com/eelume-m-series, visited 30. May 2025.

(a) IKM's R-ROV with its "garage".



(b) Saipem's Hydrone-R with Subsea Docking Station by BlueLogic[13],[14].

Figure 4.7: Examples of different types of ROV subsea garages. The pictures are reproduced with permission from IKM and Saipem, respectively.

4.5 C5. ROV with temporary subsea garage

ROVs with a "temporarily deployed" garage refer to concepts where the ROV and garage are placed on the seafloor without requiring an IMR vessel or other resources to be nearby during the ROV operations. It is referred to as a temporarily deployed garage because both the garage and the ROV can be recovered and relocated to another area if needed. The requirement for offshore personnel is reported to be low—sometimes as few as a single person is needed to deploy and recover the ROV with its garage, as well as to perform maintenance when required.

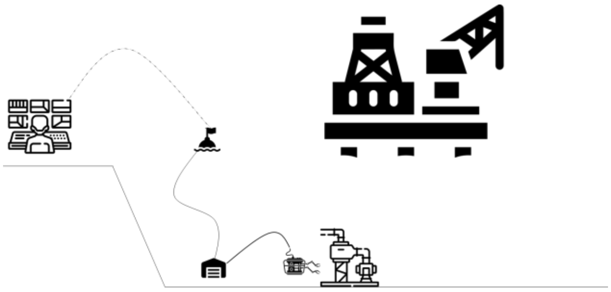


Figure 4.8: Concept sketch of ROV with temporary subsea garage.

The garage may contain a battery pack that allows for operation up to several weeks. Communication between the ROV and the control room takes place wirelessly, for example via a buoy floating on the sea surface and connected to the ROV garage by a cable. The ROV can be controlled from the ROC or from other control rooms (for example, on an IMR vessel).

An example of this technology is the *Liberty Resident System* by Oceaneering[15], see Figure 4.9. The system is used primarily for intervention-class ROVs but is also designed for use with other types of subsea vehicles. The interval between each time the IMR vessel must recover the ROV and the garage, depends, among others, on the type of ROV-IMR operations being carried out. Oceaneering, for instance, reports that the ROV was used continuously for 34 days for riser inspection without needing to recover it. [16]

[13] BlueLogic SDS, https://www.bluelogic.no/news-and-media/subsea-docking-station-sds-, visited 30. May 2025.
[14] Blue Logic Part of World Record, https://www.bluelogic.no/news-and-media/blue-logic-part-of-world-record, visited 30. May 2025.
[15] Oceaneering, Liberty Resident System, https://www.oceaneering.com/rov-services/next-generation-subsea-systems/liberty-resident-system/, visited 30. May 2025.
[16] Oceaneering, Liberty™ E-ROV demonstrates capabilities at Snorre-A, https://www.oceaneering.com/case-studies/liberty-e-rov-demonstrates-capabilities-at-snorre-a/, visited 30. May 2025.

Some strengths (+) and weaknesses (-) with the concept are:

- \+ No need for an IMR vessel except when the garage and ROV are deployed or recovered.
- \+ Can be used even when weather and sea conditions prevent IMR vessels from operating in the area, provided that the garage and ROV were deployed in advance.
- \+ Can be relocated between subsea facilities (by recovering the ROV and garage to an IMR vessel and transporting them to the next facility).
- – Needs to be recovered more frequently compared to an ROV with a permanent garage.
- – Wireless connection to the control room may in some cases reduce the quality of transmitted data (e.g., images and video).

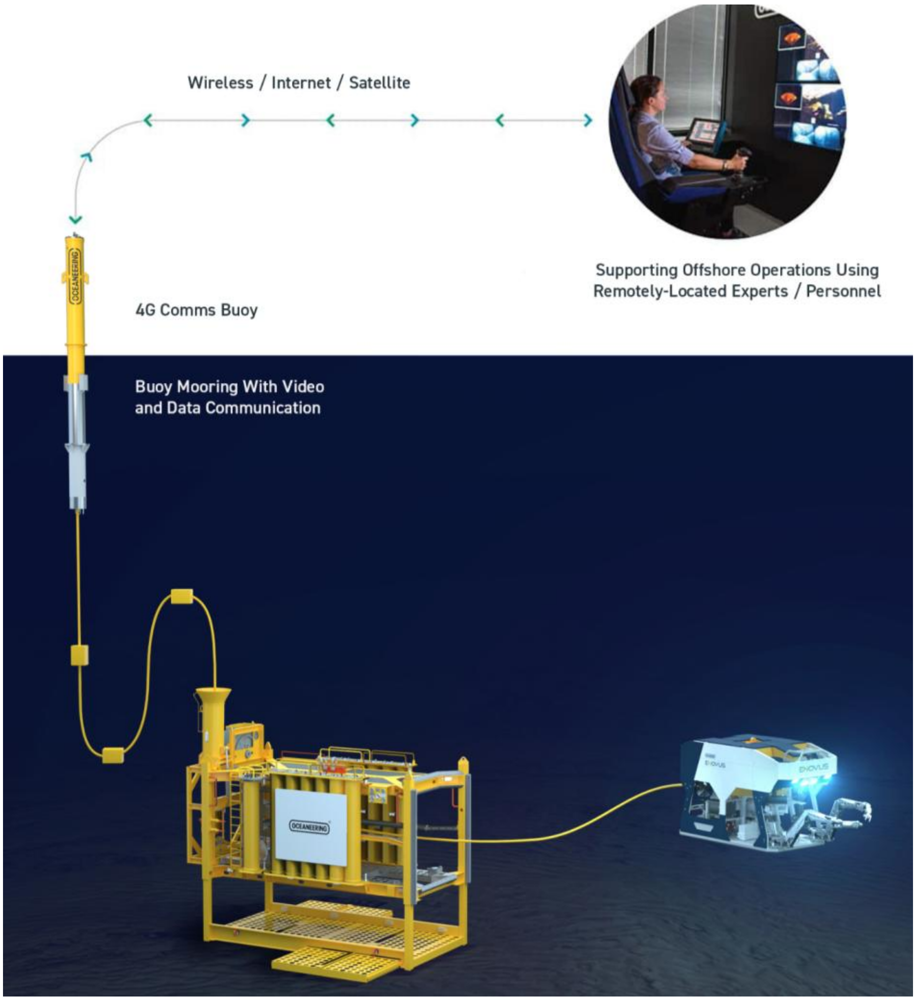


Figure 4.9: *Liberty Resident System* by Oceaneering. Picture reproduced with permission by Oceaneering.

4.6 C6. ROV deployed from shore

In this concept, the ROV is deployed from shore and moves autonomously to the offshore work area. The concept may also involve ROVs moving between different work areas. Recharging may be required while being offshore, for example through the use of charging pads, as described in Section 4.4. Onshore, some infrastructure (e.g., a crane) and personnel are needed to deploy and recover the ROV. ROVs that can be deployed from shore may also be suitable for deployment from a vessel. These ROVs primarily operate without continuous support from a surface vessel.

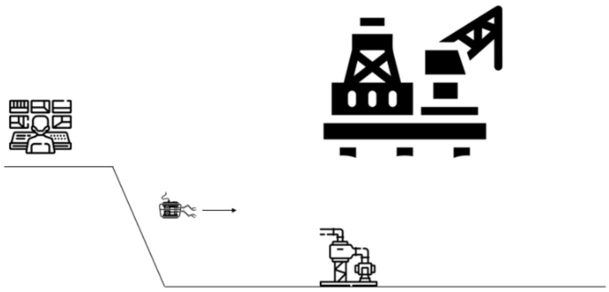


Figure 4.10: Concept sketch of ROV deployed from shore.

The ROV pilots are located onshore, either in a permanent ROC or in a mobile ROC (e.g., a container) that can be relocated together with the ROV. Since the ROVs operate over extended periods without a vessels or other communication infrastructure nearby, they are required to operate mainly autonomously. The ROVs must be able to navigate safely and efficiently, for example by following a pipeline or autonomously moving to the designated work area.

The ROVs used in this concept are hybrids between AUVs, which are designed for traveling over longer distances, and ROVs, which are developed for intervention within a limited area. Thus, these ROVs are suitable for both inspections and interventions on pipelines and locally confined subsea facilities. ROVs with the above-mentioned characteristics have already been described earlier. The *Aquanaut*[17] by Nauticus Robotics has previously focused on operations where the ROV was deployed from shore. Based on the company's website and recent news coverage (referenced in the footnote in Section 4.2), it is unclear whether this remains the focus of development, or whether the ROV is to be used in combination with, e.g., USVs. The *Freedom AUV* from Oceaneering and Saab's *Sabertooth* both have the capability to travel over longer distances and can also recharge on the way, if suitable charging infrastructure is available.

Some strengths (+) and weaknesses (-) with the concept are:

+ If the technology functions adequately, it can relieve the pilots by lessening the need for close monitoring of the ROV during missions.
– Requires advanced technology, a high degree of autonomy, as well as long-range travel capabilities and intervention capabilities.
– Very limited communication with the ROC means that the ROC does not receive continuous information on the status and progress of the mission, and inspection results only become available after the ROV has been recovered.

[17] Aquanaut by Nauticus Robotics, https://nauticusrobotics.com/aquanaut/, visited 30. May 2025.

5 Status and plans for using and developing different ROV-IMR concepts

5.1 Extent of and experiences with the different ROV-IMR concepts

5.1.1 On the Norwegian continental shelf

On the Norwegian Continental Shelf, conventional ROV-IMR operations (C1) are still predominant, estimated to account for 90-99% of all ROV-IMR operations. It is difficult to estimate the extent of use of non-conventional ROV-IMR concepts, e.g. in terms of *per kilometres of pipelines* or *number of subsea facilities inspected*. There are also significant variations among oil and gas companies, depending on their size and the types of facilities they operate.

Regarding non-conventional ROV-IMR concepts, there is growing interest and active testing on the Norwegian Continental Shelf. Most of the concepts are still under testing and development, and several qualification trials were ongoing during the preparation of this study. Most of the concepts described in Chapter 4 have been tested or applied to a certain degree. In particular, shore-based control of ROVs deployed from conventional IMR vessels (C1) is used relatively frequently today. ROVs, especially smaller units, deployed from offshore facilities (C3) are also regularly used for inspection of risers and facilities' substructures. ROV-IMR operations from USVs (C2), as well as ROVs with permanent and temporarily deployed subsea garages (C4 and C5, respectively), have been tested. The inspection results from the latter three types of ROV-IMR operations have so far been used only to a limited extent in integrity assessments. ROVs deployed from shore (C6) are in an early testing phase but are considered particularly relevant for pipeline inspection.

All oil and gas companies that participated in the interviews see potential in the non-conventional ROV-IMR concepts and are interested in their further development. Several of the companies have participated in testing the non-conventional ROV-IMR concepts, primarily C1–C5. Regarding the use of such concepts, there is a clear distinction between two groups among the companies:

- Those companies that actively cooperated with the IMR service providers to adopt non-conventional ROV-IMR concepts.
- Those companies that take a more cautious approach and wait until the concepts are sufficiently mature and qualified.

Both oil and gas companies and service providers often highlight reduced carbon footprint and lower costs as important advantages of the non-conventional ROV-IMR concepts. In some cases, reductions in carbon footprint of up to 75 % compared with conventional ROV-IMR operations have been reported[18]. In addition, shore-based ROC provide greater flexibility, more comfort, as well as a lower level of risk compared to having personnel offshore.

At the same time, some challenges are mentioned. In some geographical areas, mobile broadband coverage is limited, and one needs to rely on satellite communication systems such as Starlink, which is highlighted as a potential vulnerability. For USVs (C2), intentional disruption of satellite navigation signals (jamming) may be a challenge, particularly in the northern regions.

[18] Offshore Mag, November 2020, 'Empowered' ROV provides reliable remote monitoring option https://www.offshore-mag.com/subsea/article/14185167/oceaneering-empowered-rov-provides-reliable-remote-monitoring-option, accessed 12. June 2025.

Another challenge that was highlighted by several companies is the reliability of non-conventional ROV-IMR concepts. A system failure may result in significant downtime and delays in the IMR operation. Some concepts, however, have demonstrated high reliability over extended periods. Several fully electric systems are already available on the market or under development. Testing shows that they are as reliable, or more reliable, than conventional ROVs. For example, there is no risk of oil leakage. However, electric ROVs have lower power output. In such cases, the ROVs are equipped with hydraulic skids.

5.1.2 Internationally

Conventional ROV-IMR operations are still the standard in most regions. The oil and gas industry is generally described as conservative. Several of the interview participants consider the Norwegian Continental Shelf to be at the forefront of testing and implementing non-conventional ROV-IMR concepts. It was emphasized that initiating development and testing in Norway provides a strong basis for gaining acceptance and approval for use in other countries. As a counterexample, it was mentioned that a few years ago the United Kingdom was leading in testing autonomous IMR solutions in the North Sea.

It is to be mentioned that ROVs deployed from IMR vessels and controlled from an ROC (C1), ROV deployed from an offshore facility and controlled from an ROC (C3), and operations with ROVs that can be disconnected from the umbilical have been tested in other regions, among others in the Gulf of Mexico and in Brazil[19]. In general, there is still a need to convince oil and gas companies of the maturity and reliability of the non-conventional ROV-IMR concepts. Internationally, one must also account for regulatory differences between countries and for geopolitical risks. Not all countries will permit ROVs to be remotely controlled from another country or grant approval for the use of USVs.

5.2 Strategies, prioritisations and further plans regarding the different ROV-IMR concepts

5.2.1 Oil and gas companies

An increase in the need for IMR operations is expected, driven by the growing number of subsea facilities, the aging of existing facilities, and the associated need to follow-up these. Most oil and gas companies currently do not have an overarching strategy for the selection of ROV-IMR concepts but rather choose the option that is considered most suitable at any given time to carry out IMR tasks. One company, however, has a formalized objective of reducing the number of personnel offshore. This is also reflected in the company's contracts—for example, through requirements that at least one ROV must be controlled from shore during IMR operations.

All companies that participated in the interviews envision adopting non-conventional ROV-IMR concepts to optimize integrity management of subsea facilities. Non-conventional ROV-IMR concepts were repeatedly described as new or additional tools in the toolbox. It is therefore likely that the share of non-conventional ROV-IMR operations will increase in the future.

Many emphasized that the technology must be sufficiently qualified, i.e. through documented quality of the results. As mentioned earlier, parameters such as cost, environmental footprint, availability, reliability, maintenance requirements, and a robust communication link between the shore-based ROC and the ROVs are important.

[19] Offshore Mag, August 2023, Operators ramping up AUV/ROV efforts offshore, https://www.offshore-mag.com/vessels/article/14296152/operators-ramping-up-auv-rov-efforts-offshore, accessed 12. June 2025.

Some companies mentioned that data quality is also an important factor in the decision on the ROV-IMR concept. This is particularly the case if data only become available after the ROV operation has been completed. Likewise, if it is in any case necessary to deploy an IMR vessel to carry out maintenance, non-conventional ROV concepts may add limited value.

Regarding the availability of ROV-IMR operations, it was noted that ROVs with garages (C4 and C5) may offer an advantage during winter, when weather conditions are often too poor for launching and recovering ROVs. This could allow for improved continuity in integrity monitoring throughout the winter months.

5.2.2 System and service providers

System and service providers mainly align themselves with the needs and requirements of the oil and gas companies. This means that close collaboration between providers and oil and gas companies is essential to further develop and adapt the non-conventional ROV-IMR concepts to future needs. The trend toward shore-based control appears to be continuing. Several service providers are therefore expanding their capacities to support shore-based control of ROVs, both for operations from conventional IMR vessels (C1) and from USVs (C2).

Several needs have been mentioned by the system and service providers:

- More flexible solutions that also can be used cost efficient on small and medium sized subsea facilities.
- Integration of ROVs with permanent garages in new field developments, as an integrated part of the operational concept.
- Development of improved solutions for intervention tasks, enabling non-conventional ROVs to become more flexible and independent when using tools.

It was also pointed out that cost should not be the sole factor determining whether new technology is adopted. Other aspects, such as improved data quality, new methods for data collection and analysis, and the possibility to monitor the condition more frequently, were highlighted as factors that should be included in cost–benefit assessments.

An article in the *Offshore* magazine [27, p. 48 ff.] on ROV-IMR operations deployed from a USV describes a vision in which the ROC will be able to handle different types of systems from various suppliers. The ROC is viewed as an opportunity for increased cross-disciplinary collaboration, which could contribute to more innovative solutions. According to the article, this may lead to the establishment of new roles located in the ROC to enhance operational flexibility. Such a development will require greater collaboration and trust across industry stakeholders.

6 Evaluation of the ROV-IMR operational concepts

This chapter presents SINTEF's assessment of the non-conventional ROV-IMR concepts. Section 6.1 summarizes the main performance- and risk-influencing factors related to ROV-IMR operations. Section 6.2 builds on these and describes the assessment of changes in workflow. Section 6.3 summarizes the evaluation of non-conventional ROV-IMR concepts based on selected criteria.

6.1 Performance and risk influencing factors

Performance influencing factors can be defined as "*factors identified as having significance for […] functions and the ability of […] elements to function as intended*" [28, p. 12]. Performance influencing factors include humans, technology and organisation, as well as their interaction.

Human Factors challenges

Ho et al. [29] summarize Human Factors challenges identified in 2011, which influence the performance, efficiency and effectiveness of ROV operations. The challenges are:

- Reduced sensory cues and spatial awareness.
- Control and navigation of ROVs.
- Workload and situational awareness.
- Trust in the ROV and the ROVs reliability.

Since the article was published, efforts have been made to address these challenges. New technology has been developed and implemented, but the challenges remain relevant. One company emphasized that they have integrated control rooms on board their vessels, and that the working conditions for the ROV crews are very good, much better than working from containers, which had been the standard type of control room for many years. The physical design of control rooms is now considered improved compared to ten years ago. Consequently, many companies have modelled shore-based ROCs after those on IMR vessels or similar vessels.

Situational awareness is another central term that can be defined as: "perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" [30]. Situational awareness with respect to ROV-IMR operations includes several important aspects:

- Situational awareness among ROV pilots during an operation: Where is the ROV? Where is the umbilical? Where are other ROVs? How is the information structured on the screen?
- Situational awareness for the inspector and technical experts in interaction with the pilots: Is there a relevant finding on the screen? Where is the finding located? How has the condition changed since the previous inspection?
- Situational awareness between ROV pilots, the supervisor, company representative, offshore personnel on the offshore facility, and shore-based personnel during an ROV-IMR operation: Where is the ROV? What tasks are being carried out on the subsea facility? Is the subsea facility in a safe state? Where is the IMR vessel?

ROV-IMR operations are carried out with distributed situational awareness. This means that information is shared among multiple people and systems, providing a more comprehensive picture of the situation [31]. The theory of distributed situational awareness highlights how information is shared and how interaction takes place between different actors, or agents, within a system. Non-conventional ROV-IMR concepts may result in information being distributed among more actors, which can increase the complexity surrounding situational awareness.

New technology, humans and organisation

Some informants focused on the *advantages* of new technology. They point out that personnel can become tired and fatigued during inspections, when they may spend several days in front of a screen. It is challenging for inspectors to maintain attention and capture all details, for example during pipeline inspections. New technology can contribute to more consistent inspections, something that cannot always be guaranteed with manual ROV-IMR operations carried out by pilots. It is also emphasized that the technology is continually improving.

Certain types of facilities or specific desired inspection results may still require human intervention to detect faults, or to safely manoeuvre the ROV or other tools into the correct position. One example is the navigation of ROVs into structures that allow for a more detailed view of the internal parts of the facility. In SINTEF's assessment, it is therefore important to facilitate human use of the systems, so that these tasks can be carried out properly and with high quality.

Other informants also point to *challenges* associated with new technology. It is emphasized that fully automated data collection during inspections has its limitations. For example, additional inspections may be necessary if the quality of data is insufficient, or when specific sites need closer examination, such as in cases of suspected minor leaks or damages. If the data are only analysed after the mission, this may delay the detection of potential threats. This could result in delayed handling of such findings and weaken confidence in automated data collection.

Utne et al. [32] describe the "core contradiction" of autonomous (highly automated) operations. The core contradiction is that the higher the degree of automation, the fewer demands are placed on the pilot during normal operations. However, if something unforeseen occurs, the demands to the pilots suddenly become very high, as they must quickly understand the situation without having been closely involved earlier in the operation. Simulation and training are necessary to develop effective pilots. When developing highly automated systems, it is therefore important to take into account that ROV pilots must be able to handle such situations. Performance-shaping factors that should be considered include, for example, environmental conditions, situational awareness and alarms, type of operation, communication (including ROV control room), uncertainties, equipment, procedures, experience, and expertise, among others.

Johnsen et al. [33] provide guidance on considerations during the design phase of remotely operated systems with ROCs. User involvement is one of the key aspects. In several of the interviews, it was noted that these topics had been taken into account in the design of non-conventional concepts. However, it is not possible to conclude from the interviews whether this has been addressed in all concepts, or whether the extent is sufficient.

When one of the ROV Pilots also assumes the role of inspector, this can be challenging, as it places high demands on both precision and concentration. For example, it may be difficult to manage the umbilical while also carrying out a complex ROV-IMR operation. The cable could, for instance, become entangled with an anode, potentially causing the ROV to become stuck in an underwater structure. Inspections should therefore always include a dedicated set of eyes focused solely on the screen with the purpose of inspecting. It is argued that piloting an ROV is a complex task that requires the full attention of both ROV pilots.

It is emphasized that inspectors are responsible for the entire delivery, from data collection and reporting to updating databases, finalizing work documentation, and preparing work packages. One informant argued that the closer inspectors are to the actual work, the smaller the margin for error becomes. When the inspector is physically present, for example on board together with the ROV pilots or divers, the delivery process becomes more effective. Physical presence allows for assessing the site from multiple perspectives if the initial approach does not provide the required result, or if a finding requires further investigation.

Workload is an important factor when it comes to human performance and situational awareness [29]. Workload is defined as the "*task demand of accomplishing mission requirements for the human operator*" [34]. Workload can have both positive and negative consequences for ROV-IMR operations. It is assumed that there is an optimal workload for each task, which depends on and can be moderated by various drivers. Hooey et al. [34] describe four main drivers that influence workload:

- Environment (visibility, complexity, uncertainty, stressors).
- Task (requirements to the human, time-dependent requirements, task structure).
- Equipment (vehicle, tool, quality of data connection).
- ROV pilots (skill regarding the task, individual differences and preferences).

Regarding shore-based control of ROVs, it can be assumed that some uncertainty is reduced, as the operational environment for the pilots is more stable (no waves, good indoor climate). At the same time, it is pointed out that data transmission and associated quality are highly significant drivers of workload. Several factors are mentioned as part of this driver, including latency and latency variation, bandwidth, connection reliability, and connection availability (including corrupted or blocked signals). Variation in latency was highlighted in the conversations as a factor that is critical for precise and efficient handling of the ROV.

The importance of being able to intervene immediately was also emphasized. Reviewing video footage after a mission can work well. However, if a finding requires immediate intervention and the video is only reviewed after the vessel has left the area, this may increase risk related to both equipment and the environment. In addition, it may potentially increase costs due to renewed mobilization. On the other hand, it is not always possible to follow up findings immediately. In some cases, the ROV does not return to the same site until the next campaign.

It is also pointed out that untrained eyes – or pilots preoccupied with manoeuvring – may overlook important details. This is supported by the literature [34], which emphasizes that limited task experience and poor familiarity with the system are negative workload drivers and may lead to delays or reduced quality. Training can counteract this to some extent. In the interviews, some participants expressed that the flexibility of conducting ROV-IMR operations from an ROC may result in pilots, inspectors, and other experts working across multiple facilities in a relative short time, thereby having less experience, knowledge and familiarity with the specific facility where the ROV-IMR operations are to be performed. This would then increase the workload and could have negative consequences.

Remote control vs. offshore presence

Company representatives are increasingly located onshore, which may create challenges. Delayed communication and lower-quality video streams make it more difficult to identify problems in time. This may result in operations having to be carried out more slowly, or in observations being reviewed afterward based on recordings.

Several companies want to relocate more personnel onshore. Non-conventional ROV-IMR concepts and the increased use of shore-based ROCs leads to transferring personnel from offshore to onshore. Working-time regulations differ between offshore and onshore. When moving towards onshore ROC operations, it may be necessary to adopt a three-shift system in order to maintain 24-hour ROV operations.

One informant did not see any issue with combining eight- and twelve-hour shifts offshore and onshore, as they had extensive practice with rotation. This, however, requires adjustments to staffing strategies, work-hour arrangements, and training routines to ensure robust operations. SINTEF believes that situational awareness may be affected by this shift arrangement. When three shifts are used onshore instead of two, misunderstandings may propagate more easily. Furthermore, shifts may be staffed by different people, which can weaken continuous situational awareness. Regarding the interaction between the shore-based ROC and offshore units (IMR vessels or offshore facility), the number of contact points will increase significantly compared to before. This may contribute to unclear responsibilities and a fragmented situational awareness. Such conditions are particularly critical during intervention operations, but also during inspections that require close coordination.

Several participants in the discussions emphasized that the working environment is much better onshore, as conditions are stable (i.e. not moving) and one is not affected by bad weather or high waves. It was highlighted that working in a container is uncomfortable. Onshore, there is more space and easier access to restrooms and other facilities.

Some participants note that the physical design of the workplace is good on IMR vessels. One participant explained that ROV pilots have the same setup offshore on IMR vessels as they do onshore in the ROC, including identical chairs, controllers, joysticks, and so on. An advantage of conventional ROV-IMR operations is that personnel can more effectively shield themselves from external distractions, such as family-related stress. Another benefit of being on an IMR vessel or an offshore facility is the ability for personnel to discuss issues and get in contact with each other when needed. When people go home, to a hotel, etc., their focus tends to shift away from the job.

It was also pointed out that illness among offshore personnel can create challenges. One informant noted that this often leads individuals to delay reporting unwellness or illness. Adverse weather may create difficulties transporting personnel offshore. Onshore, it is easier to bring in additional staff when needed. It was also emphasized that working onshore is better for the work-life balance of many employees.

Several participants also highlighted the advantages of having all involved parties gathered in one room both before and during the operation (ROV pilots, inspectors, company representatives, experts, crane operators, etc.). Communication becomes simple and efficient, fostering a shared and improved situational awareness. With everyone viewing the same screen, the inspector can easily point out specific locations to be inspected or avoided. This is particularly important when working with less experienced ROV pilots, but also relevant in other situations. It was emphasized that this can prevent errors, delays, safety issues, and high costs. These benefits are especially critical during complex operations where coordination between different types of equipment, such as ROVs, vessels, and cranes, is required.

When ROVs are remotely operated from shore, these collaborative benefits are less easily achieved, which may affect both efficiency and safety in complex operations. One challenge highlighted is that if one ROV is controlled from shore and two ROVs from an IMR vessel, coordinating the operations can be demanding. This is because two ROV crews share the same room and thus have easier communication compared to communication with the third pilot onshore. A possible mitigating measure for this is to establish strict communication protocols.

The working condition of employees and ROV crews plays a significant role in how individuals – and the entire sociotechnical system – work. Regarding organizational aspects (roles, responsibilities, cooperation, etc.), most participants point out that there is little difference between the various concepts from an organizational standpoint, and that they adapt how they work. Non-conventional concepts are organizationally similar but relocated to shore. Some organizational challenges with non-conventional ROV-IMR concepts were pointed out, but these disadvantages are handled through operational planning.

6.2 Workflow in the non-conventional ROV-IMR concepts

The interviews revealed that the roles remain largely unchanged in non-conventional concepts. Primarily, personnel who are offshore in conventional ROV-IMR operations are relocated onshore. The expected changes are illustrated in Figure 6.1 below. The functions that are (partially) moved onshore are highlighted in red.

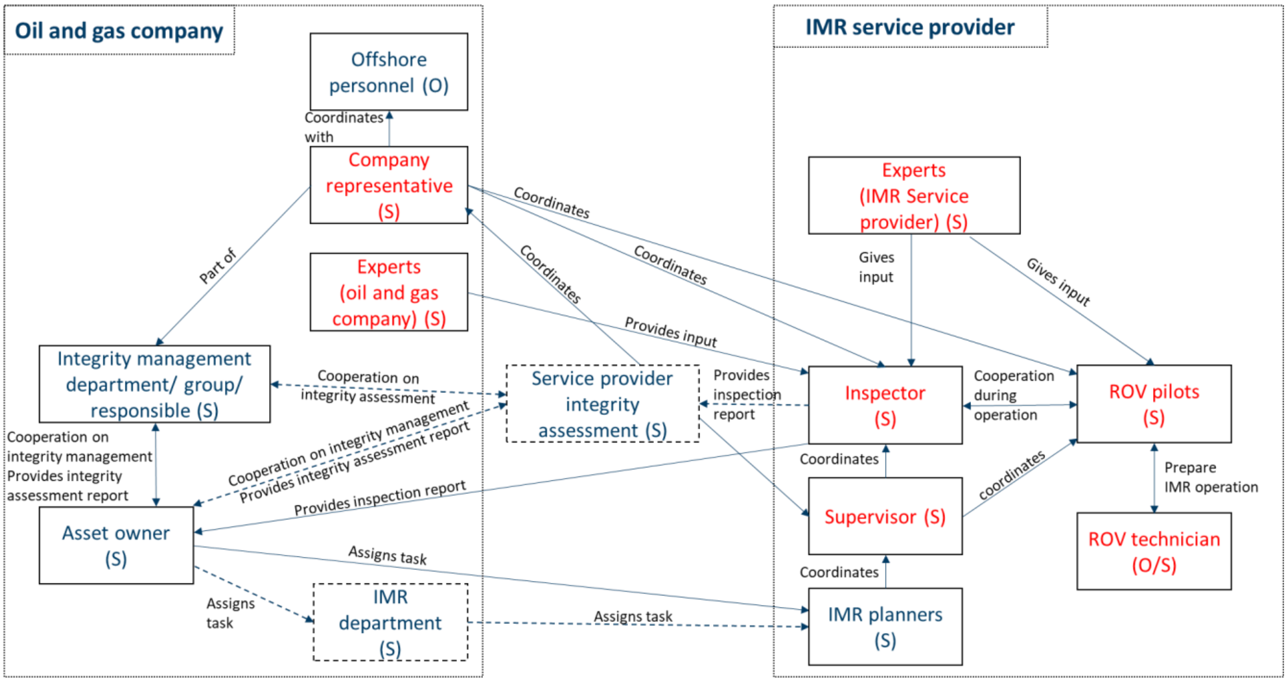


Figure 6.1: Expected changes in the stakeholders' location (red font) across the different ROV-IMR concepts (C2 through C6).

The main difference from conventional ROV-IMR operations is that the various actors are not necessarily located in the same control room. Figure 6.2 provides an overview of the non-conventional ROV-IMR concepts and the actors' locations during an ROV-IMR operation. To achieve common situational awareness, it is essential that all actors have access to high-quality video and reliable communication during IMR operations. This is particularly important for the inspector and the ROV pilots.

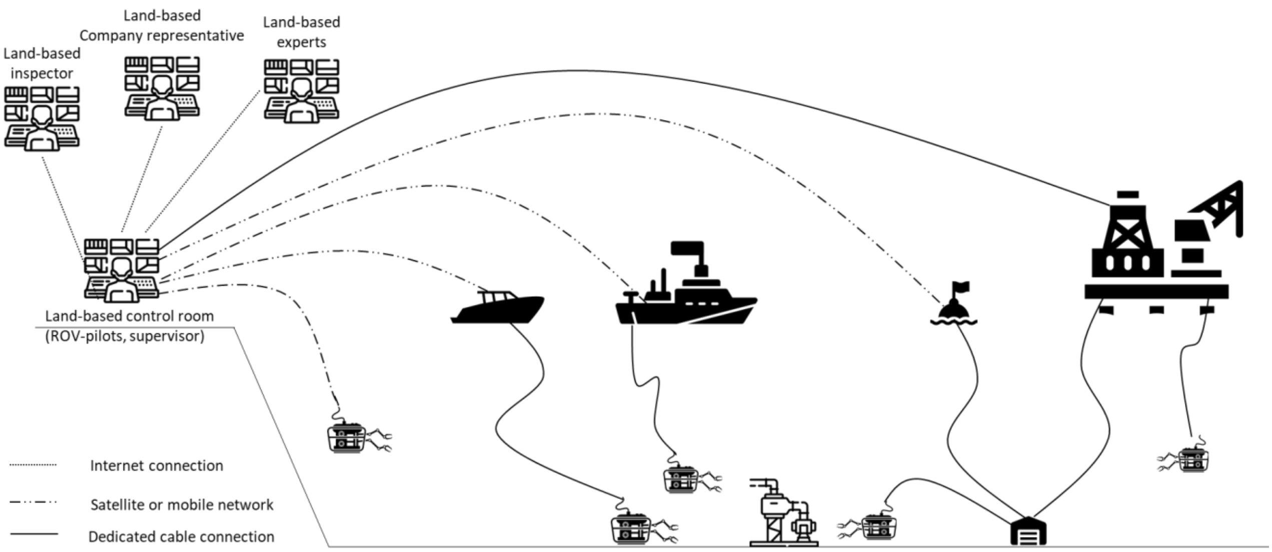


Figure 6.2: Overview of non-conventional ROV-IMR operational concepts.

To ensure effective communication, system providers have emphasized that they have developed customized communication and collaboration platforms to support high-quality communication during non-conventional ROV-IMR operations. Some operators have the option to disable unnecessary or less critical data streams to ensure good quality of video and verbal communication in case there are disturbances in data transmission. In certain cases, the use of a video stream of the control room is intended to make it easier to "point at the screen" virtually. Communication is a key factor for situational awareness in non-conventional concepts.

Inspections are already being carried out today with the inspector being located onshore. However, it was not clear whether specific communication and collaboration tools were used in all of these operations. Situations were mentioned in which the inspector did not have adequate video quality and had to perform the analysis after the inspection was completed. In these cases, the inspector had no opportunity to influence data collection or to re-examine areas of interest while the ROV is still on site. It was emphasized that the experience of the ROV pilots is important to capture such situations, both by independently identifying potentially relevant areas and by manoeuvring the ROV more slowly and closer to the inspection object.

It is necessary to have procedures in place to make ROV pilots aware when such situations occur, and to ensure that these procedures are followed and complied with. SINTEF assess that this is of critical importance. However, the interviews are not sufficient to conclude whether such routines and processes are currently in place and followed.

One advantage of having the personnel onshore that was mentioned, is that subject-matter experts only need to be present when required. They do not have to remain offshore for 14 days if they are only needed for a few days during the ROV-IMR operation itself. This may have positive effects, as they are more rested and can be more attentive during the operation. At the same time, SINTEF sees potential drawbacks. For instance, specialists and inspectors may have less time to familiarize themselves with the operation and the subsea facility. Personnel may also receive more, and different additional tasks compared to conventional offshore ROV-IMR operations. This may have a negative effect by increasing the workload.

As some interview participants pointed out, local knowledge of a subsea facility is important, and this may be lost when using non-conventional ROV-IMR concepts. In addition to having less time to familiarize themselves with tasks and facilities, frequent switching between different facilities may lead to a loss of both local knowledge and situational awareness. When ROV pilots, inspectors, and specialists must switch between facilities this can occur relatively quickly in a shore-based ROC, for example, after completing another inspection at a different site. Consequently, each individual needs time to reorient themselves, understand their current location, and identify potential differences from the facility inspected earlier the same day. This constitutes a potential source of misunderstandings and errors, particularly if facilities are confused with one another. Older facilities are especially vulnerable, as they may be poorly (inaccurately) documented, and in such cases both prior experience-based knowledge and sufficient time for information sharing among stakeholders are required.

Another aspect concerning workflow and situational awareness is the availability of ROVs and necessary tools. In most non-conventional ROV-IMR concepts (C2, C4, C5, C6), no ROV technician is nearby, and only the tools and sensors already mounted or available in the subsea garage or the USV can be used. This may mean that certain ROV-IMR operations can only be carried out from conventional IMR vessels (which usually have a workshop with spare parts on board), because the correct tool is not otherwise available. As a result, operational delays may occur when maintenance or tool changes cannot be performed quickly on site. System providers are therefore developing concepts for changing tools either subsea (C4, C5) or on board the USV (C2) to mitigate this challenge.

The non-conventional ROV-IMR concepts will also affect workflow during inspections and interventions that require coordination with the offshore facility. Examples include opening subsea hatches with a crane, ROV interventions on valves, and similar tasks. In such cases, it is essential that ROV pilots, the supervisor, the company representative, and offshore personnel share a common understanding of both the task to be performed and the specific situation. When ROV pilots operate from shore and are therefore located far from the offshore facilities, communication and mutual understanding may become more challenging. A frequently raised issue concerning shore-based control is that individuals without offshore experience do not always understand the physical offshore environment or the potential consequences of their decisions.

As discussed earlier in Chapter 5.2.2, one industry stakeholder pointed out that new roles are likely to emerge in the future as a result of the introduction of non-conventional ROV-IMR concepts. These roles will nevertheless have to cover current and future responsibilities arising from changing work practices and technological solutions. However, it is difficult to predict exactly what types of roles will develop and how they may affect collaboration, information flow, and responsibilities in the operations, beyond what has been described in this study.

6.3 Comparison between non-conventional and conventional ROV-IMR concepts

The methods, roles, and human–machine interfaces used offshore today are to a large extent used also in non-conventional concepts (the ROCs). Key differences are that personnel are distributed across multiple locations, operations are more dependent on data connections (latency and bandwidth) between offshore and onshore, and there are differences in regulations concerning working hours and employment conditions. In general, ROV pilots, inspectors, and others are expected to be more rested due to shorter working hours and improved conditions onshore (no waves, better sleep, etc.). This may lead to higher-quality data collection compared to conventional ROV-IMR operations, provided that data quality is maintained. Table 6.1 summarizes key differences between conventional and shore-based ROV-IMR operations.

Table 6.1: Comparison of conventional and shore-based ROV-IMR operations with focus on situational awareness. (+) signifies possible positive effects on situational awareness. (-) signifies possible negative effects on situational awareness.

Conventional ROV-IMR operations from IMR vessel	Non- conventional IMR-ROV operations from ROC	Possible consequences that affect situational awareness when operating from shore
12-hour shifts, two weeks offshore	8-hour shifts, Monday to Friday	+ Less fatigue, more attentive - More frequent shift handover - More people to coordinate with
More focus on the job, closer to colleagues	Can take better care of family life, home after the workday	+ Improved work-life balance - Reduced focus on the job
Waves, movement, little space	Fixed control room, fully climatised	+ Improved physical work environment - Long "distance" to the offshore environment
Illness will affect the whole operation	Possibility to call in quickly a substitute if needed	+ More flexibility, better work conditions - More people can be involved in the operations
Possibility to directly point at screens and to interact with the ROV pilots	Limited possibility to directly/ physically interact between personnel	+ Stakeholders can easily be connected when needed - Possibility for more misunderstandings, less communication
Little delay on screen	Possible variation of latency and display quality on screens	- Worse video quality, delays in data analysis, possible need for follow-up inspections

Situational awareness during data collection has the greatest impact on the integrity assessment. Disruptions in data communication may prevent some stakeholders from monitoring the operation. This can delay the integrity assessment, as the collected data material only becomes available after being transferred onshore. In such cases, relevant findings may be overlooked unless the ROV pilots have sufficient experience and skills to identify them without input from the inspector. In SINTEF's view, this may weaken the facility's integrity if delays and deficiencies in data quality are not compensated through technical or organizational measures.

When communication between the ROV and the ROV pilots is disrupted, they have reduced control over the ROV, which may affect both data collection (inspection) and interventions, while situational awareness may also be diminished (c.f. Chapter 6.2). In SINTEF's view, strong situational awareness and close coordination between the shore-based ROC and the offshore facilities are required to avoid misunderstandings that could lead to accidents, for example, the wrong valve being opened, or offshore personnel being unaware that an intervention is being done. When interventions cannot be carried out, this results in delays to maintenance or repairs, which may compromise the integrity of the facility.

If communication between the ROV and the ROC is lost, this can be temporarily compensated for, for example through the ROV holding its position or returning to the garage or a rendezvous point. If communication with the ROV cannot be re-established (concepts C3-C6), a conventional IMR vessel or similar will need to be mustered to recover the ROV and carry out the integrity assessment. This will result in a significant delay in the integrity assessment and in the follow-up of the integrity management program, which may in turn compromise integrity.

Table 6.2 summarizes the different non-conventional ROV-IMR concepts and evaluates them against conventional ROV-IMR operations from an IMR vessel.

Shore-based control of an ROV deployed from an IMR vessel (C1) is very similar to conventional ROV-IMR operations. Limitations such as those mentioned above regarding loss or disruption of communication can be partially compensated for by the crew on board.

ROV deployed from a USV (C2) is also very similar to conventional ROV-IMR operations. Damages on the ROV and loss of communication may be more challenging.

ROV deployed from an offshore facility (C3) may have advantages compared to conventional operations. As mainly lighter ROV are used, the possibilities are limited.

ROVs with permanent subsea garage (C4) are not limited by size but is less flexible with regard to tools and maintenance. Disruptions or loss of data communication are less relevant, since communication is transmitted through a reliable dedicated cable between the offshore facility and onshore (provided that the facility is equipped with such a cable).

ROV with temporary subsea garage (C5) is more flexible than concept C4, being bound to one field or facility. At the same time, satellite or mobile networks serve as the communication carrier, which may lead to challenges similar to those for ROVs deployed from USVs (C2). In addition, the possibilities for maintenance and the availability of tools may be limited for ROVs deployed from USVs (C2) and ROVs with garages (C4 and C5).

ROV deployed from shore (C6) stand out as being less mature than the other non-conventional concepts. There is also considerable variation in possible designs and the capabilities of these ROVs. The distance from shore will have a significant impact on operations. Disruptions or loss of communication may easily result in loss of the system and of the collected data. Challenges associated with shore-deployed ROVs will be similar to those faced by other concepts that rely on satellite or mobile networks as communication carriers.

In summary, it must be ensured that the chosen ROV-IMR concept matches the criticality of the operation, so that the appropriate tools and resources are available. This is a prerequisite for inspections and interventions to be carried out within acceptable timeframes and to avoid compromising asset integrity, including in cases where unforeseen events occur during the operation. As highlighted in Chapters 6.1 and 6.2, this requires a holistic approach to the design and implementation of the ROV-IMR operational concept. When taking non-conventional ROV-IMR concepts in operation, one needs to assess the operational and emergency procedures, and training tailored to the specific needs, and the potential challenges that may arise during the operations. This requires close follow-up from service providers, system suppliers, and the oil and gas companies to ensure that operations are conducted with sufficient robustness and safety.

Table 6.2: Non-conventional ROV-IMR concepts compared to conventional ROV-IMR operations. It is assumed that the ROV pilots are located in an ROC.

Criterion	C1. ROV deployed from IMR vessel, operated from ROC	C2. ROV deployed from USV	C3. ROV deployed from an offshore facility	C4. ROV with permanent subsea garage	C5. ROV with temporary subsea garage	6. ROV deployed from shore
Maturity level	Very mature, regularly in use	Field trials finished and under qualification	Common to control an ROV from the facility, tested with ROC	Tested several months, under qualification	Tested several months, under qualification	Under development, prototype trials
Data transmission between ROC and offshore receiver	Satellite or mobile network	Satellite or mobile network	Wired cable connection to the offshore facility	Wired cable connection to the offshore facility	Satellite or mobile network	Direct data transmission between the ROC and ROV through satellite, mobile network or hydroacoustic connection
Data transmission between the offshore receiver and the ROV	Umbilical between the vessel and ROV	Umbilical between the vessel and ROV	Umbilical between the offshore facility and ROV	Umbilical or hydro-acoustic connection between the garage and ROV	Umbilical or hydro-acoustic connection between the garage and ROV	
Flexibility regarding ROV location	Same as conventional	More flexible, depending on the concept	Less flexible	Less flexible	Same as conventional	More flexible, depending on the possible range
Flexibility regarding sensors, tools and types of operations	Same as conventional	Same as conventional, if the necessary tools are on board the USV	Same as conventional	Same as conventional, if the necessary tools are in the garage, dependent on concept	Same as conventional, if the necessary tools are in the garage, dependent on concept	Same as conventional, highly dependent on the design of the ROV
Availability of personnel and experts	Increased availability	Increased availability	Increased availability	Increased availability	Increased availability	Lower availability
Frequency of inspections	Same as conventional	Same as conventional	More frequent possible	More frequent possible	More frequent possible	Dependent on the design
Mustering time	Same as conventional	Shorter	Shorter	Shorter	Shorter if the garage is already in the area	Shorter
Possibility to maintain the ROV	Same as conventional	Reduced possibility, requires return to port	Same as conventional, requires that spare parts are available on the offshore facility	Reduced possibility, ROV and garage need to be retrieved with a vessel	Reduced possibility, ROV and garage need to be retrieved with a vessel	Same as conventional, if the ROV can be recovered
Availability of data after data collection	Same as conventional	Same as conventional, longer waiting time if data link is disrupted	Shorter	Shorter	Shorter	Same as conventional, or longer waiting time, depending on the design

7 Conclusion and recommendations

The report describes and assesses non-conventional ROV-IMR concepts, with a focus on concepts that use shore-based Remote Operations Centres (ROCs). This is based on interviews with the industry and insights from scientific theory and publications. The various non-conventional ROV-IMR concepts have strengths and weaknesses compared to conventional ROV-IMR operations, which must be considered when planning ROV-IMR activities. Disruptions and loss of communication between the ROV and the ROC, and between the ROC and other stakeholders, will affect the execution of integrity assessments and represent a risk. Latency, bandwidth, and the risk of data loss must be evaluated for each concept and type of operation. Stable and robust communication is crucial to ensuring good situational awareness and high-quality data collection.

The interviews with the industry reveal differing views on conventional and non-conventional ROV-IMR concepts. Oil and gas companies report mixed experiences with non-conventional concepts. Most of the respondents are positive toward the development of non-conventional concepts and technologies, but some also point to challenges. The prevailing attitude in the industry is that the best available solution should be used. What constitutes the best solution will depend on how oil and gas companies prioritize the various performance parameters characterising an ROV-IMR operation. SINTEF sees the potential for non-conventional ROV-IMR operations to improve the integrity of subsea facilities by enabling more frequent and targeted inspections. The question is whether this potential will be realized through more frequent and improved inspections, or if it will be used to reduce costs.

The choice of an ROV-IMR concept must be based on a holistic assessment of the operational requirements, threat landscape, criticality, and available technology. The correct selection and application of an ROV-IMR concept have a direct impact on the integrity management of a subsea facility. Communication disruptions or other technical limitations that result in delayed or inadequate data collection will weaken the foundation for the integrity assessment and may lead to deferred maintenance or errors in risk assessment. It is therefore essential that the choice of the concept is supported by the requirements to integrity management regarding quality and robustness.

Most of the non-conventional ROV-IMR concepts described in the report are still being tested and under qualification. At the same time, remote operation of ROVs from shore-based ROCs with the ROV being deployed from an IMR vessel, has become common practice. This development reflects the industry's need for an increased level of shore-based operations.

The industry emphasizes that ROV-IMR operations are largely carried out as before, but with the use of new technology and with personnel relocated onshore. However, in SINTEF's assessment, non-conventional ROV-IMR operations will nevertheless entail changes in the interaction between humans, technology, and organization. This requires that the technology is qualified for human use, and that the associated work processes also undergo qualification. If human and organizational aspects are not adequately addressed, this may increase the operational risk and, over time, weaken the integrity of the subsea facility.

It is essential that oil and gas companies, service providers, and system suppliers share a common understanding of the strengths and limitations of the various concepts, such that the technologies are adopted appropriately. In this process, managers as well as ROV pilots, inspectors, and other relevant stakeholders should be involved, ensuring that end-users are aware of both the capabilities of the technologies and their own role within the system.

The transition to shore-based ROCs for ROV-IMR operations entails several potential challenges related to Man–Technology–Organization (MTO) perspective and Human Factors, which must be addressed to ensure safe and effective operations. Some of these challenges have already been taken into account by system suppliers in the design of their solutions.

However, SINTEF has not been able to determine to which extent the users have been involved in the development of the non-conventional concepts currently being tested. User involvement in such processes is essential to ensure that the solutions are perceived as practical and that they support the operators' needs and tasks. This is particularly important when personnel are spread out across several locations and have different needs for information, such as ROV pilots, inspectors, and personnel on the offshore facilities.

Regardless of the degree of involvement to date, it is crucial to ensure that non-conventional ROV systems are implemented in an appropriate and safe manner. By applying the principles of Human Factors Engineering in both the design and operational phases, it is possible to optimize both human performance and the overall efficiency of the system. This is achieved by developing solutions that are intuitive, safe, and supportive of the user's situational awareness and decision-making.

7.1 Further work

This study has certain limitations. The report has primarily focused on shore-based ROCs and has to a limited extent addressed other relevant technological developments, such as the use of Virtual or Augmented Reality, artificial intelligence for threat identification, and the increasing degree of autonomy in subsea operations. SINTEF recommends conducting a systematic review of these technologies to assess their potential impact, both positive and negative on integrity assessments. Such a review could contribute to a better understanding of how emerging technologies affect the interaction between humans, technology, and organizations, and may provide a basis for the further development of robust and safe solutions.

In the interviews with the industry, participation from ROV pilots was limited. This is a weakness, as these pilots possess significant knowledge and experience related to ROV-IMR operations and collection of data for integrity assessments. As a result, their operational perspectives have been obtained only to a limited extent. SINTEF therefore recommends conducting a dedicated study on the experiences, viewpoints, and expectations of ROV pilots regarding the use of non-conventional ROV-IMR concepts. The MTO perspective and the perspective of distributed situational awareness should be included in such a study. This could provide valuable insight into how these concepts affect the practical execution of operations and the quality of integrity assessments. In particular, how different roles, technological interfaces, and the flow of information influence shared situational awareness and decision-making.

Visual inspection with cameras and inspection using sonar are the most commonly applied methods in current IMR operations. In the interviews with the industry and the document review, several limitations of these methods were identified. One example is the assessment of sacrificial anodes, which may often appear intact during visual inspection, even though they are in fact nearly depleted. SINTEF therefore recommends conducting a study to evaluate the effectiveness of different inspection methods, with particular emphasis on their ability to provide an accurate picture of the condition and integrity. Such a study could contribute to more reliable integrity assessments and form the basis for improved inspection practices.

It was also pointed out that the way integrity assessments are reported and stored can be improved. Today, the reports are delivered as PDF documents, which can make it challenging to monitor the integrity status over time. New and alternative solutions that better visualize the development of a facility's integrity should therefore be explored and considered.

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