



<https://doi.org/10.31217/p.40.2.9>

TRIZ – Driven Design of Inspection ROVs for Offshore Oil and Gas Infrastructure

Pavel Shcherban*

Immanuel Kant Baltic Federal University, Institute of High technologies – ul. General-leytenantova Ozerova, 57, Kaliningrad, Russian Federation, e-mail: ursa-maior@yandex.ru

* Corresponding author

ARTICLE INFO

Original scientific paper

Received 5 December 2025

Accepted 17 February 2026

Key words:

ROV

Technical optimization

Offshore oil and gas infrastructure

TRIZ

Quality management

Equipment design

ABSTRACT

The development of the oil and gas sector, particularly offshore production and transportation, requires the creation of a wide range of diagnostic equipment capable of inspecting risers, pipelines, and platform foundations under challenging conditions. Elements of this infrastructure may be exposed to strong currents, high water turbidity, great depths, seabed burial, or biological fouling. As a result, the use of standardized remotely operated vehicle (ROV) configurations is often impractical. It leads to a set of challenges spanning the design of marine vehicles as well as the resolution of physical, technological, and software-related problems, including optimization of equipment placement and layout. During the design of an ROV, engineers must address issues related to power supply, buoyancy, hull strength, communication systems, installation of control and monitoring instruments, integration of diagnostic equipment, and the principles for data handling and storage. These parameters are typically interdependent, which necessitates multivariate analysis and comprehensive optimization. The study develops and presents a method for optimizing the parameters of an ROV intended for the inspection of risers and offshore oil and gas platform foundations, based on TRIZ (Theory of Inventive Problem Solving). The existing regulatory framework for ROVs is incorporated, the types of optimization tasks are identified, and the necessary input data sets are examined. The work demonstrates how combining TRIZ principles with multifactor optimization methods can yield an optimal design and layout solution for an ROV. As a result, TRIZ methods have been adapted to the problem of designing ROVs for the inspection of offshore oil and gas facilities.

1. Introduction

The development of mineral resources in the World Ocean has been rapidly accelerating in the 21st century: new production platforms are being commissioned, and subsea infrastructure—oil and gas pipelines, risers, and other systems—is being expanded. This progress is driven by a technological revolution marked by the emergence of innovative materials, new structural solutions, and advanced software capable of performing complex load calculations and modeling the behavior of offshore structures in the marine environment.

At the same time, the number of offshore infrastructure facilities continues to grow. Many of them, especially those built in the 1970s–1990s, require regular diagnostics, assessment of technical condition,

and eventually safe decommissioning [1]. New facilities also require continuous monitoring. Performing such tasks underwater is practically impossible without the use of Remotely Operated Vehicles (ROVs) [2]. Over the past decades, a substantial body of literature and practical experience on underwater vehicle design has been developed. However, the challenges involved in creating such systems remain complex and multifaceted. They include selecting the optimal hull configuration, arranging onboard equipment, designing power supply architectures, communication and control systems, and many other components [3]. The final design depends on the intended purpose of the ROV and its operating conditions. This reduces the number of viable options, yet still leaves a wide field for engineering exploration [4].

From a structural standpoint, ROVs required for the inspection of risers and elements of offshore oil and gas platforms differ significantly from ROVs intended for “standard” underwater operations. In the vicinity of risers and load-bearing platform structures, localized turbulent flows arise due to the interaction of the ambient current with vertical and inclined structural elements. The vehicle operates under confined-space conditions, characterized by small inter-pipe clearances, a high probability of mechanical contact, and the need to maintain a specified position relative to the inspected object for extended periods of time.

Conventional remotely operated underwater vehicles are typically designed to perform a wide range of tasks (inspection, manipulation, tool transportation) and are optimized for universal operating conditions. As a result, such vehicles exhibit excessive mass, dimensions, and power characteristics, while their control systems are primarily oriented toward motion in open space rather than high-precision positioning in close proximity to complex engineering structures. During the inspection of risers and offshore platform elements, these characteristics lead to reduced inspection accuracy, increased energy consumption, and a higher risk of collisions with structural components. Therefore, this study focuses on developing tools that support the selection of optimal engineering and design solutions for ROVs intended to assess the technical condition of offshore oil and gas infrastructure. Establishing such a methodological framework should simplify the work of designers, improve the quality of engineering decisions, and provide more structured guidance for scientific inquiry [5]. Before formalizing combinatorial optimization tasks within ROV design, it is necessary to examine the regulatory documents governing their development and operation, as well as the initial data provided by the customer—typically an oil and gas company. Analysis of these materials helps define the boundaries of the design process and, figuratively speaking, outline the search space for the optimal engineering solution [6].

Within this defined space, the next stage consists of the engineering search itself, which involves solving a series of optimization tasks. Several approaches to organizing this process exist. One of the most established and widely applied is the Theory of Inventive Problem Solving (TRIZ). TRIZ includes problem formalization, identification of functional deficiencies, algorithmizing of scientific search, and the use of methods for resolving physical contradictions. Applying TRIZ makes the design process significantly clearer and more structured, while the contradiction-elimination techniques align naturally with optimization procedures.

The objective of this study is to assess the feasibility of applying the TRIZ methodology to the design of specialized ROVs for the inspection of offshore oil and gas facilities. The primary function of the ROVs considered

is defined as the inspection of offshore oil and gas infrastructure, including visual surveys, acquisition of diagnostic information on the condition of riser structures and platform foundations, as well as precise positioning of measuring and observation instruments in close proximity to the inspected elements. As a result, priority is given to requirements related to the control system, maneuverability, flow stability, energy efficiency, and the arrangement of diagnostic equipment, which renders the use of unified or standardized design solutions ineffective.

Using TRIZ principles, we develop an algorithm for solving optimization tasks during the design of an ROV intended for the inspection of offshore oil and gas facilities. By defining the sequence of design stages and the set of tasks addressed at each step, we outline the possible directions for optimization-oriented engineering search.

2 Input data and standards. General procedure for designing ROVs for the for the inspection of offshore oil and gas facilities.

Operations on the seabed are carried out under conditions of high hydrostatic pressure gradients, low temperatures, strong currents, limited visibility, and the absence of natural lighting [7,8]. The combination of these factors imposes increased requirements on the design, reliability, power supply, and controllability of remotely operated underwater vehicles (ROVs) and, as a rule, leads to partial unification of design solutions. At the same time, there are currently no unified international standards that comprehensively regulate the design and application of ROVs for all classes of underwater tasks [9,10], which leaves room for variable engineering approaches in the development of specialized vehicles.

The most formalized regulatory requirements relate to offshore oil and gas facilities and subsea production systems. In particular, ISO 13628-8 (ROV interfaces on subsea production systems) and ISO 13628-9 (ROV/ROT intervention systems) define requirements for interfaces, allowable loads, and conditions of interaction between ROVs and elements of subsea infrastructure, including risers, pipelines, and wellhead equipment. The requirements of these standards directly influence vehicle configuration, the selection of working tools, positioning systems, and permissible operating modes. In addition, the formulation of requirements takes into account provisions of standards and recommendations governing the design and operation of offshore oil and gas structures, including ISO 19901 (loads, reliability, and operating conditions of offshore structures), ISO 19906 (arctic offshore structures), as well as the practical guidelines DNV-ST-N001 and DNV-ST-*, which specify requirements for strength, stability, and safety of

subsea structures and pipeline systems. These documents define the limiting external conditions (hydrodynamic loads, vibrations, temperature regimes) that must be considered when designing ROVs intended for the inspection of such facilities.

Alongside international standards, national and industry-specific documents are also applied: in the Russian Federation—rules of the Russian Maritime Register of Shipping and GOST R 60.7.0.2-2022 for work-class ROVs; in Norway—NORSOK U-102; as well as standards and guidelines of classification societies (e.g., DNVGL-CG-0264) [12,13]. These documents regulate permissible operating depths, requirements for hull strength, power supply systems, umbilical cables, launch and recovery operations, and industrial safety issues.

Within the framework of this study, regulatory documents are considered not as sources of specific design solutions, but as a set of constraints and boundary conditions that define the feasible design space of ROV configurations. These constraints are incorporated into the problem formulation at the pre-design stage and are used in forming the set of admissible solutions in multi-criteria optimization tasks. Such an approach makes it possible to reconcile the requirements of the regulatory framework for offshore oil and gas facilities with the TRIZ methodology, while preserving the potential for identifying rational and innovative engineering solutions. Based on the analysis of the presented standards,

a procedure for determining the main characteristics of ROVs will be developed with reference to the requirements of ISO 9001:2015, particularly Sections 8.3.2–8.3.5 (Figure 1).

The design of any product, including an ROV, is a process of transforming customer requirements, regulatory standards, and operational conditions into specific technical characteristics. A key part of this process is the implementation of mechanisms for design control, validation, verification, and the establishment of feedback loops between designers, manufacturers, and users [14].

In the development of an ROV, the following sequence of steps should be followed. First, the customer defines the functional requirements for the ROV. Upon receiving these requirements, the designer determines the input parameters for design and development. This includes specifying operational conditions such as working depths, duration of deployment, type of communication with the surface, list of operational tasks, and dimensions. It is recommended that the stated requirements be prioritized. Once the boundary values are defined, the designer proceeds to the second stage – solving optimization tasks. At this stage, it is necessary to achieve the highest possible quality and performance characteristics of the ROV within the defined limits (or with minimal deviations based on a priority matrix). The full range of mathematical and software-based ana-

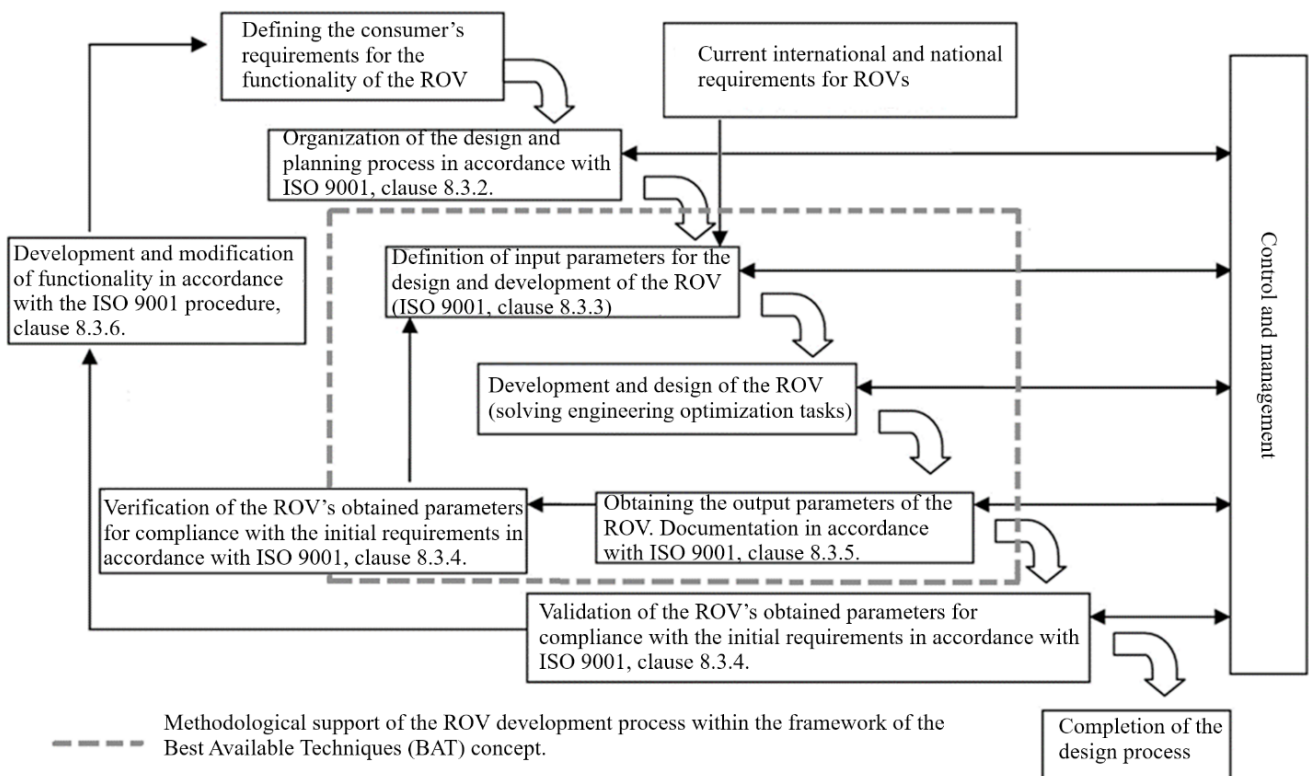


Figure 1 Organization of the ROV design process (Based on ISO 9001:2015)

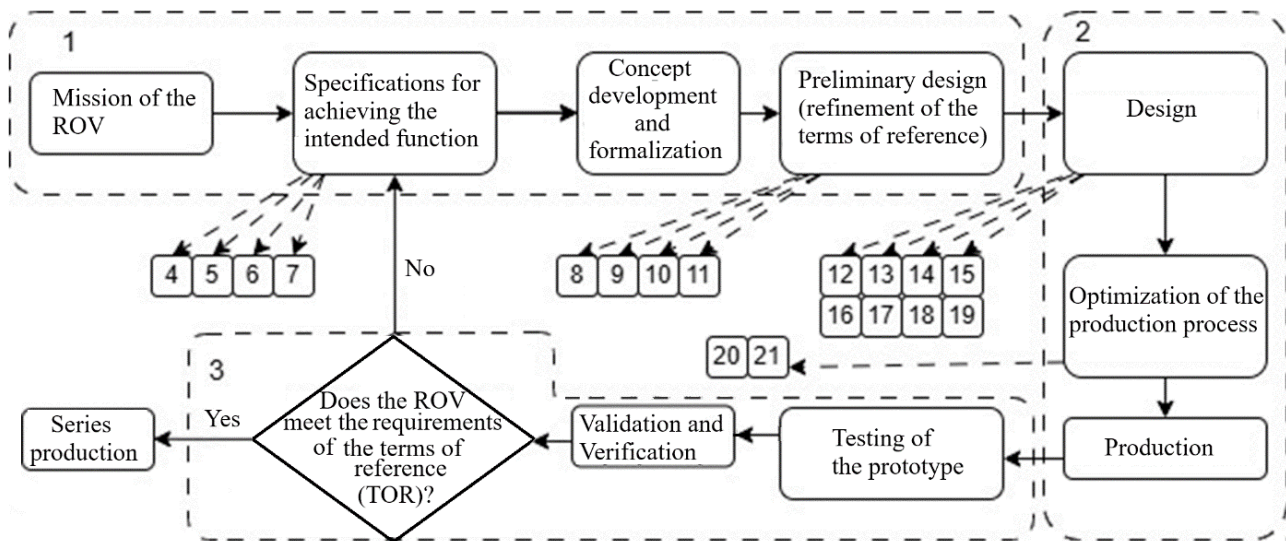


Figure 2 The ROV design process and the key tasks addressed at each stage

1 – Development of the technical specification and preliminary design work; 2 – Design and manufacturing; 3 – Testing and transition to series production; 4 – Definition of system requirements based on the ROV mission (inspection/repair of risers and offshore platforms); 5 – Determination of key operational characteristics to meet system requirements; 6 – Estimation of preliminary production costs; 7 – Identification of upgrade and future development points for the ROV project; 8 – Establishment of system performance criteria; 9 – Determination of the minimum system cost; 10 – Definition of minimum and maximum dimensions and weight of the ROV; 11 – Specification of requirements for transportation, storage, and deployment of the ROV; 12 – Hull design (strength calculations); 13 – Design of the power supply system; 14 – Design of the ROV propulsion system; 15 – ROV positioning and navigation design; 16 – Development of software and remote control systems; 17 – Arrangement and connection of ROV working tools; 18 – Placement of ROV lighting systems; 19 – Design of ROV launch and recovery systems; 20 – Standardization and unification of the ROV hardware base; 21 – Quality control of the production process

lytical optimization methods can be applied to find optimal solutions.

Based on the developed design solutions, technical documentation is prepared, and the resulting operational characteristics are subsequently verified against the stated requirements, thereby closing the quality loop. In the event of design errors or new requests from the customer, the process is repeated [10]. In this study, particular attention is given to the stages of defining functional requirements, organizing the design process, determining input parameters, and solving optimization tasks. These stages are critical because they directly shape the ROV's design and, through the search for optimal solutions, ensure that the vehicle meets the customer's requirements as fully as possible [10]. The ROV design procedure can also be viewed not only from the perspective of the classical quality loop but also from the production standpoint. In this context (Figure 2), the stages of the process may differ slightly, although the principles of development and the presence of feedback remain unchanged.

In the process of designing ROVs intended for the inspection of offshore oil and gas facilities, several example tasks are considered (13,14, Figure 2), within which it is possible to carry out procedures for searching optimal design solutions using the TRIZ methodology. A set of mathematical and analytical methods is presented

that enables the solution of such problems in design, engineering, and optimization.

3 Approaches to ROV design using TRIZ combined with multicriteria optimization

The process should begin with an analysis of the system requirements – including diving depth, mission duration, maneuverability, payload capacity, level of autonomy, communication channel bandwidth, resistance to pressure, temperature, and salinity, as well as energy consumption. From the TRIZ perspective, the first step is to identify the technical contradictions arising between these characteristics [15]. For ROV design, Altshuller's matrix-based approach can be applied. This method provides a systematically validated way to resolve engineering contradictions that inevitably occur during the operation of complex technical systems. The matrix approach allows designers to move from intuitive solution search to a structured selection of design directions. By determining which parameter needs improvement and which one may be negatively affected, the engineer refers to the corresponding cell in the matrix, which lists inventive principles that have proven effective in similar conflicts. These principles serve as heuristic guides in generating solution variants and steer thinking toward non-obvious yet technically feasible approaches.

Table 1 Contradiction matrix for the configuration of ROVs for the inspection of offshore oil and gas facilities.

Improving Parameter / Worsening Parameter	Mass of Moving Object	Energy Consumption	Reliability	Ease of Control
Power	10, 29, 2	1, 18, 38	11, 35, 1	15, 28
Maneuverability	15, 29, 40	6, 19	1, 3	-
Strength	1, 35	28, 34	-	3, 17
Dimensions	-	1, 26	2, 3, 35	15, 17

Where: 1 – Segmentation; 2 – Extraction; 3 – Local Quality; 6 – Universality; 10 – Preliminary Action; 11 – Cushion in Advance (Buffering); 15 – Dynamics; 17 – Transition to a New Dimension; 18 – Mechanical Vibration; 19 – Periodic Action; 26 – Copying; 28 – Replacement of a Mechanical System; 29 – Pneumatics and Hydraulics; 34 – Discarding and Recovery; 35 – Change of Physical or Chemical Properties; 38 – Use of Strong Oxidizers; 40 – Composite Materials [15].

An example of a fragment of the technical contradiction matrix adapted to the tasks of developing ROVs for the inspection of offshore oil and gas infrastructure is presented. Vertically, the matrix lists the parameters to be improved, and horizontally, the parameters that could potentially worsen as a result. At each intersection, the matrix specifies the numbers of inventive principles that have demonstrated effectiveness in analogous situations. This fragment covers typical conflicts between energy efficiency, maneuverability, weight, strength, and reliability – characteristics critically important for offshore ROV operations (Table 1).

Each cell contains a list of inventive principle numbers from the classical TRIZ set [15]. In practice, the most technically feasible and tested methods were considered. It should be noted that Altshuller’s full matrix contains 39 technical parameters and 40 inventive principles, requiring a comprehensive comparison and analysis of all possible combinations.

The selection of optimization criteria and their prioritization in this study were carried out based on the specifics of inspection operations in the vicinity of risers and elements of offshore oil and gas platforms, where precise positioning, stability, and energy efficiency during prolonged hovering are of primary importance. For example, in the considered case it is evident that increasing the power of an ROV designed for the inspection of offshore oil and gas facilities leads to an undesirable increase in its mass. To address this problem, the matrix recommends considering the principles of preliminary action (10), the use of pneumatic and hydraulic systems (29), as well as extraction (2). These principles indicate possibilities such as relocating heavy functional units outside the main hull, pre-assembling hardware modules before deployment, or replacing traditional electromechanical drives with lighter hydraulic systems. In the case of a conflict between maneuverability and energy consumption, principles such as Universality or Mechanical Vibration can be applied. This may suggest, for example, implementing adaptive control systems or vibration-based drives to reduce overall energy consumption during maneuvering. When attempt-

ing to increase strength without adding mass or reducing controllability, methods such as Local Quality Improvement (Principle 3), Material Structure Modification (Principle 35), or selecting differentiated structural solutions based on local loads are appropriate.

Continuing the previous example of increasing the battery for greater ROV autonomy, which leads to increased weight, we can also observe a decrease in maneuverability and an increase in hull size. To resolve such multifaceted contradictions, the TRIZ method of eliminating contradictions without compromise can be applied. The contradiction can be formulated as follows: “We want to increase the ROV’s operational autonomy (improvement) without increasing its mass (deterioration).” According to TRIZ, appropriate inventive principles are then selected—for example, Segmentation, Extraction, and Inversion [16]. At this stage, it is useful to employ the concept of the Ideal Final Result (IFR). For instance: “The ROV operates indefinitely without needing energy replenishment and has no mass.” From this ideal, ideas emerge such as using external power sources, cable charging, energy recovery from water flow, and other approaches.

From the perspective of mathematical formalization, the design of ROVs within the TRIZ methodology can be represented as a multi-objective optimization problem. In each design variant generated using TRIZ inventive principles, an implicit system of objective functions is defined, reflecting the effort to resolve identified technical or physical contradictions. In general, the design problem reduces to finding values for a set of objective functions, the contradictions between which are to be resolved using TRIZ methods [17].

Formally, the set of design solutions can be denoted as $x \in X$, where X is the set of permissible system configurations, determined by the choice of structural and functional parameters of the ROV. Each configuration x is associated with a vector of objective functions $\vec{f}(x) = (f_1(x), f_2(x), \dots, f_n(x))$, each corresponding to one of the key performance criteria of the vehicle, defined by its primary purpose — the inspection of offshore oil and gas facilities.

The feasible solution space X is formed by a system of constraints, including operational, regulatory, and structural requirements. These constraints cover operational depth, vehicle dimensions and mass, energy budget, reliability and safety requirements, as well as limitations imposed by conditions near offshore oil and gas installations. The set of design variables is generated based on solutions obtained using TRIZ inventive principles, which define permissible options for the configuration, layout, and functional structure of the ROV. As an example, consider the following criteria.

For example, let $f_1(x)$ be the system mass (to be minimized), $f_2(x)$ be autonomy (to be maximized), $f_3(x)$ be manufacturing or maintenance cost (to be minimized), and $f_4(x)$ – be the diversity of observation and diagnostic tools on the ROV (to be maximized). The design problem then reduces to the search for the minimum of the following vector function:

$$\min_{x \in X} \vec{f}(x) = (f_1(x) - f_2(x), f_3(x) - f_4(x)) \quad (1)$$

Unlike scalar optimization, there is no single absolute minimum in this case. Instead, the concept of Pareto optimality can be used [18]. A parameter vector $x' \in X$ is called Pareto-optimal if there does not exist $x \in X$, such that $f_i(x) \leq f_i(x')$, for all $i \in \{1, 2, \dots, n\}$, and there exists at least one index j , for which the strict inequality $f_j(x) < f_j(x')$, also holds. In other words, no solution can

be improved in all criteria simultaneously without worsening at least one of them.

The set of such solutions forms the so-called “Pareto front” — a hypersurface in the objective function space that separates the region of feasible but suboptimal solutions from the region of solutions at the efficiency frontier (Figure 3). Visually, in the two-dimensional case, this front can be represented as a concave curve, each segment of which corresponds to a particular trade-off between two competing criteria [18].

This approach aligns well with the conceptual framework of TRIZ. Pareto optimality describes the boundary of feasible trade-offs within a fixed system architecture, whereas TRIZ is focused on identifying and eliminating the underlying contradictions that give rise to these trade-offs. For example, in a conflict between mass and autonomy, the Pareto method is limited to finding a balance between energy source capacity and structural mass, while TRIZ offers a way to go beyond the compromise by applying principles such as “segmentation,” “extraction,” or the use of environmental resources (e.g., harnessing energy from surrounding water).

In practice, before developing a fundamentally new solution using TRIZ, it is necessary to determine where the boundary of the system’s compromise possibilities lies in its current configuration. In this sense, Pareto

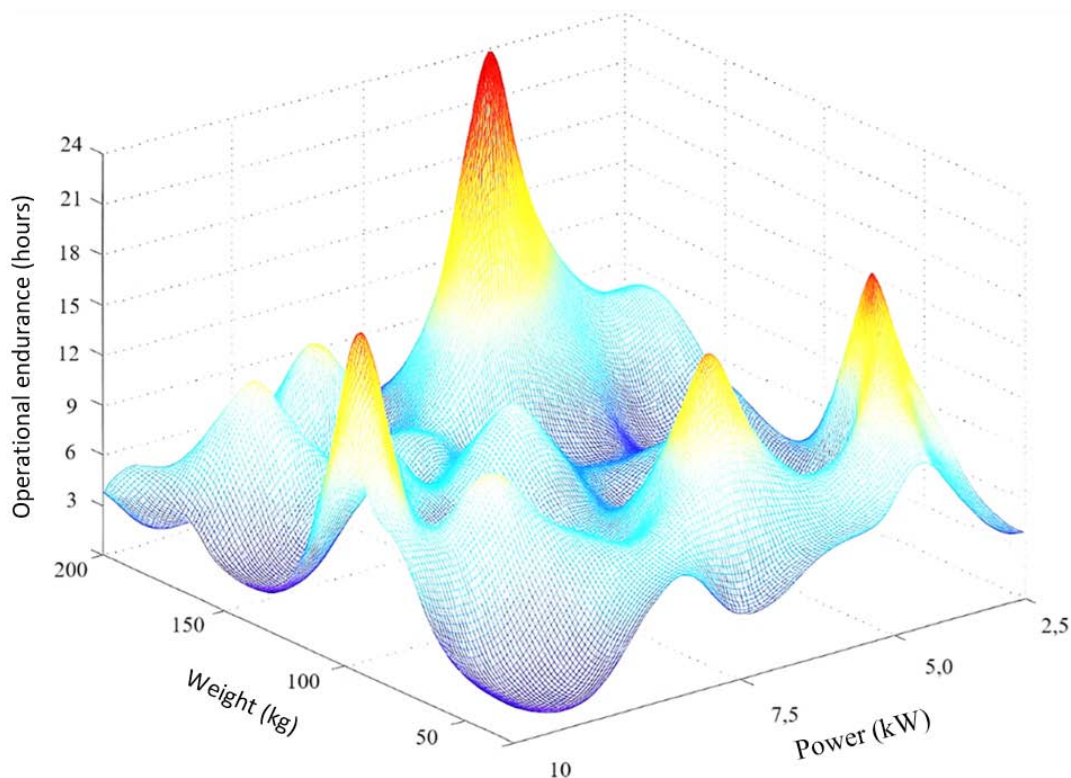


Figure 3 Example of a Pareto hypersurface in the objective function space during the preliminary design study of a ROVs for the inspection of offshore oil and gas facilities.

analysis serves an analytical function, allowing the limits of efficiency of the existing architecture to be identified [19]. Regions of the design space beyond the Pareto front correspond to areas with potential for applying TRIZ inventive principles.

To select a single specific solution from the set of Pareto-optimal configurations, a scalarization method can be applied, based on the introduction of a generalized scalar objective function:

$$F(x) = \sum_{i=1}^n w_i f_i(x) \quad (2)$$

where: w_i are the weighting coefficients reflecting the priority of each criterion.

However, this approach requires correctly assigning the weights and may shift the result toward solutions that do not lie on the Pareto front itself. An alternative is the so-called utopian point method, in which ideal (but practically unattainable) values are specified for each criterion $\vec{f}_{id} = (f_1^*, f_2^*, \dots, f_n^*)$, and then a search is performed for $x \in X$, that minimizes the distance to this point:

$$d(x) = \|\vec{f}(x) - \vec{f}_{id}\| = \sqrt{\sum_{i=1}^n (f_i(x) - f_i^*)^2} \quad (3)$$

This method is more neutral, as it does not require specifying weights and operates on the principle of minimizing losses across all directions simultaneously.

The connection of this approach with the Algorithm for Inventive Problem Solving (ARIZ) is direct. Within ARIZ, technical and physical contradictions are formulated, the Ideal Final Result is defined, and the available system resources are identified, after which solutions are generated using inventive principles [20]. Pareto-based multi-objective optimization allows the analytical stage of this process to be formalized by defining the limits of the current generation system's capabilities. If even the best Pareto-optimal solutions do not meet the requirements, TRIZ provides a methodology for transitioning to a new system architecture and developing fundamentally different design solutions [21].

Thus, within the framework of this study, the design problem of ROVs is formulated as the task of determining the set of Pareto-optimal configurations $X_p \subset X$, obtained as a result of multi-objective optimization over the vector of criteria $\vec{f}(x)$. The set X_p reflects the extreme trade-offs between the key performance characteristics of the vehicle within a fixed system architecture.

The selection of a specific design solution is carried out at a subsequent stage by reducing the multi-objective problem to a scalar one, using either the scalarization method or the utopian point method, depending on

the requirements and priorities of a particular ROV inspection mission. In this case, the optimal solution is defined as:

$$x = \arg \min_{x \in X} d(x) \quad (4)$$

where the function $d(x)$ is defined by expression (3), with the subsequent selection of a preferred configuration from the set of Pareto-optimal solutions, taking into account the vehicle's intended purpose and the priorities of the inspection mission.

Unlike traditional approaches to ROV design, which rely on proven structural schemes and standardized solutions, the presented methodology combines multi-objective optimization with TRIZ principles. In conventional design, improving a single key parameter, such as autonomy or mass, is often accompanied by deterioration in other characteristics, and opportunities for fundamentally altering the architecture are limited by the boundaries of existing trade-offs. The TRIZ methodology allows for the systematic identification and resolution of such technical and functional contradictions. When combined with Pareto front analysis, this approach not only enables the assessment of the limits of existing compromises but also identifies points for qualitative system improvement, where one objective can be enhanced without directly compromising others. Thus, TRIZ expands the design solution space, opening possibilities for innovative changes at early design stages and formalizing the process of transitioning from compromise solutions to radically improved configurations.

Next, the potential application of the proposed approach for designing ROVs intended for the inspection of offshore oil and gas facilities will be considered. Examples will be provided to demonstrate how the methodology allows formalizing the process of selecting optimal design solutions.

4 Exploring the application of TRIZ in designing ROVs for inspecting an offshore oil and gas facilities

Designing ROVs intended for the inspection of risers and components of offshore oil and gas platforms is a multi-objective engineering task, in which systemic contradictions are combined with a high degree of environmental uncertainty. Under conditions of limited space, variable currents, high hydrostatic pressure, and stringent positioning accuracy requirements, the vehicle must combine compact dimensions, maneuverability, energy autonomy, disturbance resistance, and low operational cost [14].

Unlike multi-purpose work-class ROVs, which are designed to perform manipulation, assembly, and auxiliary operations in relatively open underwater spaces, inspection ROVs operate primarily in close proximity to complex engineering structures. For these vehicles, crit-

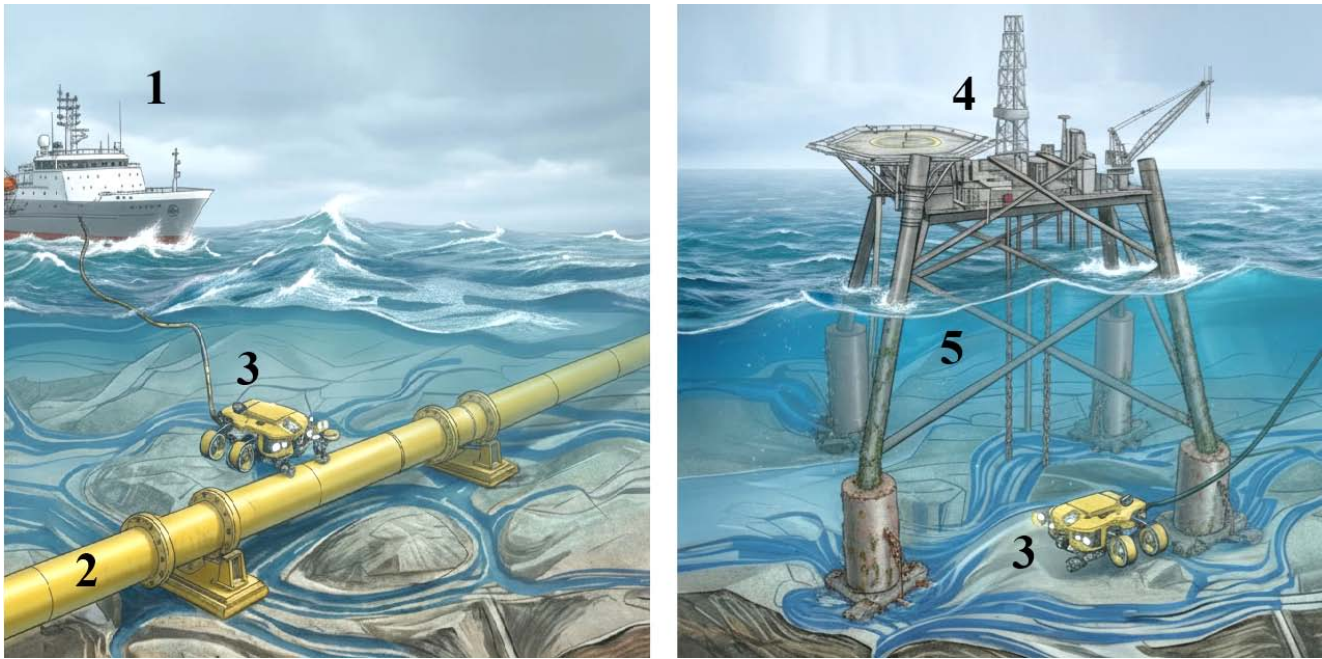


Figure 4 Inspection of offshore oil and gas facilities, pipelines, and platform foundations using ROVs.

1 – Support vessel; 2 – Subsea pipeline; 3 – ROV; 4 – Offshore platform; 5 – Platform foundation

ical factors are not thrust or lifting capacity, but rather positioning accuracy, stability in turbulent flows, compactness, minimization of hydrodynamic disturbances, and the ability to hover for extended periods in a fixed position. These operational features give rise to a specific set of technical contradictions, the resolution of which using TRIZ differs from the tasks typical of standard work-class ROV design. In this context, the following examples illustrate solutions relevant to vehicles intended for inspection missions in the vicinity of risers and offshore platforms (Figure 4).

At the TRIZ level, the analysis is conducted by identifying and resolving a technical contradiction of the form: if $A \downarrow \Rightarrow X \uparrow$, then simultaneously $A \downarrow \Rightarrow B \downarrow, C \downarrow$, where A is the ROV's mass, X is maneuverability, B is energy capacity, and, C is stability in flow conditions. In TRIZ logic, such a model can be transformed by applying resolution principles: function extraction (for example, placing energy sources outside the hull), segmentation (modularity), universality (combining steering and propulsion elements), as well as the use of physical effects (for example, variable stiffness of the hull materials, adjusted depending on depth).

Let us consider in practice the contradictions that arise when determining the configuration of the ROV's propulsion system and power supply.

We begin with the layout and placement of the ROV's thrusters. The theoretical set of solutions generated using TRIZ tools is denoted as $S = \{S_1, S_2, \dots, S_n\}$, each representing a specific configuration aimed at resolving one or more contradictions. However, not all of these solu-

tions will be rational in terms of the trade-off between criteria such as mass, precision, stability, cost, and energy efficiency [23].

These criteria are key in defining the solution space for the propulsion system of an ROV. Energy efficiency characterizes the specific energy consumption of the propulsion unit during maneuvers and position stabilization. Positioning accuracy determines the ROV's ability to maintain a specified spatial position relative to a riser or platform element under current conditions. Mass reflects the impact of the layout on overall buoyancy, transportability, and permissible load on launch and recovery systems. Stability indicates the propulsion system's operational steadiness under turbulent disturbances and its fault tolerance in the event of partial thrust loss. Cost accounts for both the complexity of manufacturing the propulsion system and the anticipated expenses for maintenance and repair. Physically, however, it is impossible to satisfy all criteria simultaneously.

Therefore, an evaluation system based on the Pareto optimality method is introduced. Let each design S_i be evaluated by a vector $f^i(S_i) = (f_1, f_2, \dots, f_k)$, where each f_j corresponds to a specific criterion. Then a solution S_i is considered Pareto-optimal if there does not exist another S_j , such that $f_j(S_j) \geq f_j(S_i)$ for all j and strictly better for at least one criterion. For illustration, a comparative table of design solutions obtained using various TRIZ principles can be provided (Table 2). At the next level, a multi-criteria normalized Pareto evaluation is performed, forming Table 3.

Table 2 Propulsion system layout solutions for ROVs intended for the inspection of offshore oil and gas facilities based on TRIZ principles

Solution	TRIZ Principle	The idea implemented in the solution	Innovation Level
S_1	Extraction	Placement of thruster modules on pivoting consoles outside the hull	Architectural
S_2	Universality	Integration of thrust control and stabilization	Functional
S_3	Dynamism	Implementable adjustment of geometry and direction of vector thrust	Configurational
S_4	Local Quality	Differentiated placement of thrusters according to functional zones	Systemic

Based on the resulting Pareto evaluation table, the next analytical step is to rank the Pareto-optimal solutions for the ROV's thruster layout, taking into account weighting coefficients for the criteria, which can be assigned using the Analytic Hierarchy Process (AHP). For the targeted design of an ROV operating under conditions of riser and offshore platform inspections, a typical priority of criteria can be defined [14].

Thus, positioning accuracy for the ROV in the inspection of risers and platform components is a critically important parameter, so we assign it a weighting coefficient of $w_1 = 30$. Energy efficiency is also significant, considering the large number of zones to be inspected, so we assign it $w_2 = 25$. Reliability is essential during ROV operation under turbulent currents near the platform base, and we assign it $w_3 = 20$. The ROV's mass affects buoyancy, ergonomics, and logistics constraints [23], but it is not as critical as the previous factors, so we assign it $w_4 = 15$. Cost, given the custom nature of the ROV, will already be substantial, so it is assigned the lowest weight, $w_5 = 10$.

Let us introduce an overall utility (evaluation) function for each solution in the form of a weighted sum of normalized values:

$$U(S_i) = \sum_{k=1}^5 w_k \cdot f_k(S_i) \quad (5)$$

where: w_k is the weight of the criterion, and, $f_k(S_i)$ is the normalized score of the criterion for solution S_i .

Using the presented formula, the specified criterion weights, and the previously developed TRIZ-based solutions, we calculate the efficiency values for each propulsion layout and configuration. To demonstrate the procedure for calculating the overall utility, consider solution S_2 . Given the assigned criterion weights ($w_1 = 30$, $w_2 = 25$, $w_3 = 20$, $w_4 = 15$, $w_5 = 10$), the integrated utility function is defined as:

$$U(S_2) = 0,30 \cdot 0,90 + 0,25 \cdot 0,80 + 0,20 \cdot 0,70 + 0,15 \cdot 0,65 + 0,10 \cdot 0,55 = 0,7625 \quad (6)$$

It should be noted that the presented propulsion layout solutions are specifically tailored for the inspection of risers and offshore platform elements and are less applicable to standard work-class ROVs. In conventional ROVs, the propulsion system is typically optimized for translational movement in open water and compensation for relatively uniform currents, with positioning accuracy achieved through excess power and vehicle mass [24].

In riser inspection conditions, this strategy proves ineffective. Local turbulent flows, reflected jets from cylindrical structures, and narrow inter-pipe gaps require the ROV to perform micro-positioning corrections with minimal energy expenditure. Therefore, solutions based on the principles of "universality" and "dynamic functionality," which combine thrust and stabilization functions, become a priority specifically for inspection vehicles. For work-class ROVs, similar solutions are often impractical due to increased reliability requirements for tool transport and the execution of force-intensive operations.

Table 3 Pareto-based multi-criteria evaluation of ROV thruster layout solutions

Solution	Energy efficiency	Accuracy	Mass	Stability	Cost
S_1	0,85	0,70	0,60	0,75	0,50
S_2	0,80	0,90	0,65	0,70	0,55
S_3	0,75	0,85	0,95	0,60	0,40
S_4	0,70	0,65	0,50	0,80	0,85

Using the presented formula, the assigned criterion weights, and the TRIZ-generated solutions, we calculate the efficiency values for each thruster layout and placement solution. Thus, the overall ranking indicates solution S_2 as the most balanced in terms of the criteria, with the highest total utility. Its distinctive feature is the implementation of TRIZ Principle №6 (“Universality”), achieved through the constructive integration of propulsion and steering functions within a single drive system. Overall, this eliminates the need for additional stabilizers and steering mechanisms, reducing the ROV’s mass and dimensions. Simultaneously, by using of integrated drives with vectored thrust, stability is ensured under turbulent flow conditions, along with the capability for precise six-degree-of-freedom positioning. The results of the integrated utility function calculation for the considered propulsion layout options are presented in Table 4.

Table 4 Optimal TRIZ-Based design of ROV propulsion systems for offshore riser and platform inspections.

Solution	S_1	S_2	S_3	S_4
Integrated utility function $U(S_i)$	0,7125	0,7625	0,745	0,690

The technical configuration of the optimal ROV corresponding to solution S_2 , includes a composite, hydrodynamically balanced hull with neutral buoyancy, capable of passing through confined inter-pipe clearances. The propulsion system consists of six vector-controlled thrusters that perform both thrust and stabilization functions, eliminating the need for separate steering systems (Figure 5).

Let us consider the second problem, specifically the design of the power supply subsystem of ROVs for the

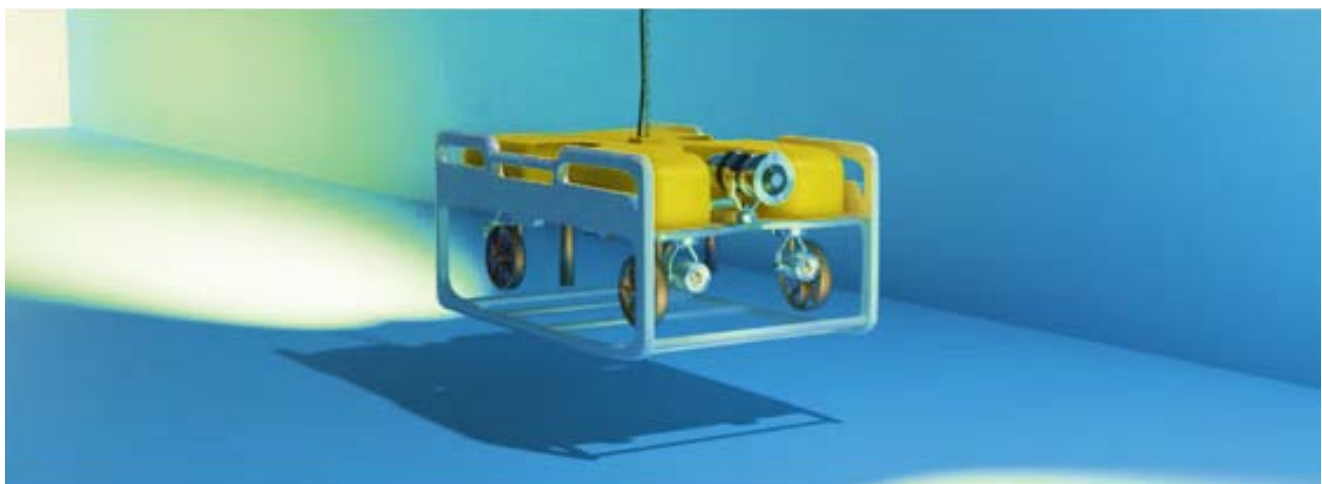
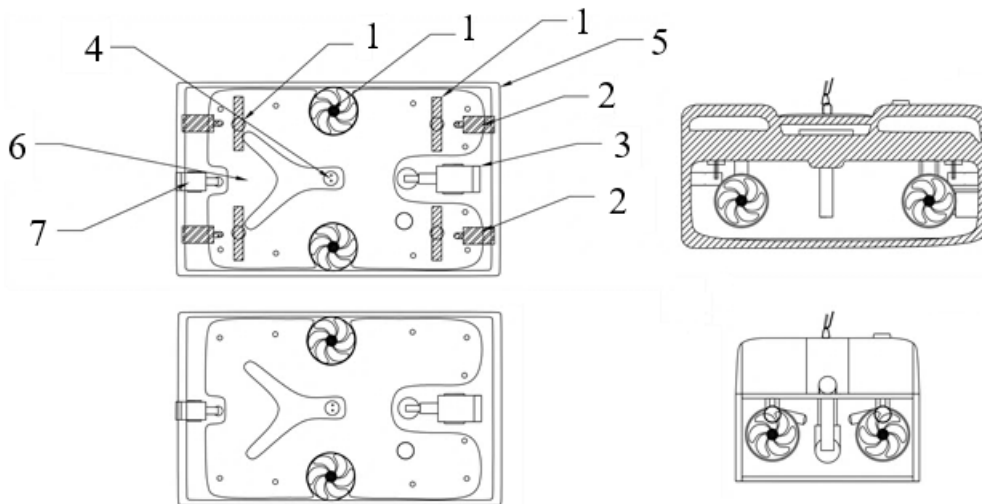


Figure 5 Example of ROV thruster placement according to the selected layout solution.

1 – ROV thrusters; 2 – Lighting units; 3 – Main camera; 4 – Launch-and-recovery tether mount; 5 – Frame; 6 – Top cover; 7 – Rear-view camera

inspection of offshore oil and gas facilities. The desire to increase the vehicle's autonomous operating time implies increasing the battery capacity, which leads to greater mass, larger dimensions, and higher system cost. An alternative is cable-based power supply; however, a long power umbilical creates significant drag and reduces maneuverability, especially in the complex geometry of platform piping and structural elements. A systemic contradiction arises: increasing energy efficiency and autonomy requires a larger energy reserve, but traditional solutions result in reduced controllability and mobility in confined spaces [25].

In TRIZ terms, this situation is formalized as a technical contradiction of the form: if $A \uparrow \Rightarrow X \uparrow$, then simultaneously $A \uparrow \Rightarrow B \downarrow, C \downarrow$, where A is the capacity of the power system, X - is the duration of autonomous operation, B is maneuverability, and, C is resistance to external mechanical disturbances. Such a contradiction is subject to resolution using various TRIZ principles (Table 5).

Each of the solutions has both advantages and limitations. For example, solution S_1 reduces the load on the ROV itself but increases the load on the cable and reduces maneuverability. Solution S_2 is technologically efficient but requires an additional mechanism for battery handling and replacement, which increases mechatronic complexity. Solution S_3 , based on the "intermediary" principle, is implemented in the form of a deployable garage module lowered from the surface vessel, which simultaneously serves as a shelter, charging station, and buffer between the vessel and the ROV. It resolves multiple conflicts at once. Solution S_4 involves installing a stationary charging point directly on the platform but is constrained by the geometry of the structure.

The specific operational requirements of inspection ROVs for offshore oil and gas facilities significantly influence the design of the power supply subsystem. Unlike conventional ROVs, which typically operate with continuous power via a tether and perform tasks near a support vessel, inspection vehicles often must operate in areas with complex structural geometry, where a long tether increases the risk of entanglement, adds hydrodynamic loads, and reduces maneuverability [25].

For the inspection of risers and platform foundations, scenarios often involve the ROV repeatedly moving between structural elements, holding position, and performing extended measurements. Under these conditions, solutions that minimize the mechanical impact of the tether on the vehicle and allow for reduced tether length become especially important. Consequently, solutions based on the principles of "intermediary" and "preliminary action" (e.g., using an intermediate garage module) prove more effective for inspection ROVs than for standard work-class vehicles, where such architectural complications are often unnecessary [24].

A multi-criteria evaluation of the solutions was carried out according to the following parameters: energy efficiency, reliability, mass, maneuverability, and technological complexity. All values are normalized (Table 6).

The weighting coefficients for the criteria are also determined using the Analytic Hierarchy Process (AHP). The highest weight ($w_3 = 30$) is assigned to the reliability of the power supply system, as a power failure critically affects the ROV's return and mission safety. The second most important parameter ($w_2 = 25$) is energy efficiency. The mass of the power system ($w_4 = 20$), af-

Table 5 Power supply subsystem layout solutions for ROVs intended for the inspection of offshore oil and gas facilities based on TRIZ principles

Solution	TRIZ Principle	The idea implemented in the solution	Innovation Level
S_1	Extraction	Relocating the battery pack to the surface; cable power	Architectural
S_2	Self-service	Built-in system of swappable batteries with mechanical extraction	Functional
S_3	Intermediary	Use of an intermediate relay module ("garage")	System-level
S_4	Preliminary Action	Recharging at a docking station mounted on the platform	Configurational

Table 6 Pareto-based multi-criteria evaluation of ROV power supply subsystem solutions

Solution	Energy Efficiency	Accuracy	Mass	Stability	Cost
S_1	0,85	0,80	0,60	0,55	0,50
S_2	0,75	0,85	0,70	0,65	0,55
S_3	0,90	0,90	0,85	0,80	0,65
S_4	0,70	0,75	0,65	0,70	0,60

fects buoyancy and stability. Maneuverability (accuracy) has a relative weight ($w_1 = 15$), as it is partially compensated by the control software. Technological complexity and implementation cost ($w_5 = 10$) are given minimal consideration. As a result, using formula (5), along with the criterion weights and TRIZ-derived solutions, we calculate the efficiency values for each configuration solution of the ROV power supply subsystem. The final integrated utility values for the power supply subsystem solutions are presented in Table 7.

Table 7 Optimal TRIZ-based design of ROV power supply subsystems for riser and offshore platform Inspections

Solution	S_1	S_2	S_3	S_4
Integrated utility function $U(S_j)$	0,695	0,735	0,835	0,705

Solution S_3 , based on the use of an intermediate module ("garage"), received the highest overall utility score. This configuration allows the power and life-support systems to be housed in a separate protected module deployed from the surface vessel, from which the ROV emerges only for the duration of the inspection. The module is designed to allow recharging, diagnostics, and temperature stabilization. ROV power is supplied, if necessary, via a short flexible cable that does not impose significant load [25]. This solution minimizes the load on the ROV itself, increases stability, and reduces the risk of

cable snagging or breakage in challenging hydrotechnical conditions (Figure 6). Additionally, the module can be equipped with a data relay system, reducing the requirements for the ROV's radio link.

Thus, the presented examples of applying TRIZ demonstrate not abstract design techniques, but targeted methods for resolving the specific contradictions that arise in the design of inspection ROVs operating near risers and offshore oil and gas platforms. For general-purpose work-class ROVs, similar contradictions either do not exist or have different priorities, leading to fundamentally different architectural solutions.

By combining TRIZ principles with various mathematical tools, it is possible to solve design and engineering optimization tasks both for the ROV as a whole and for its individual modules or components. By generating optimal configurations, the customer's requirements can be best satisfied. It is important to note that the resulting solution must not conflict with the current regulatory and technical documentation for ROVs. On the other hand, if during the design process the engineer identifies an exceptionally advantageous solution whose implementation is limited by existing standards, procedures for reviewing and amending the standards should be initiated. This is possible according to the previously described procedures. Thus, it is rational to use TRIZ for searching design solutions tailored to specific conditions and operational purposes of ROVs, such as those intended for inspecting risers and the foundations of offshore drilling platforms.

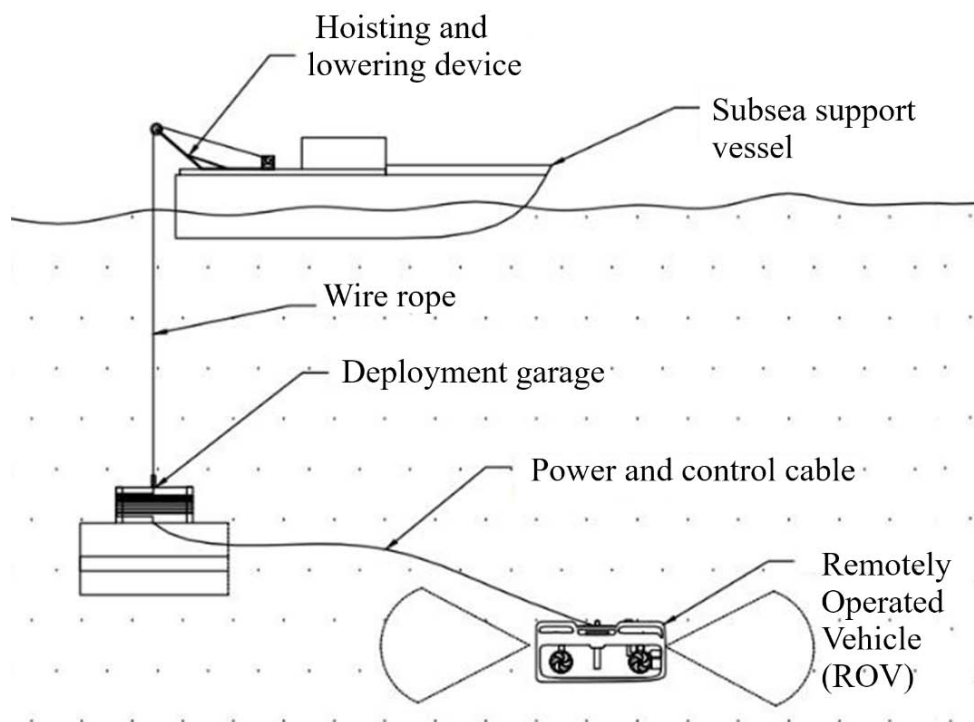


Figure 6 Example of ROV power supply subsystem placement according to the selected layout solution

5 Conclusion

The conducted study comprehensively analyzed the applicability of TRIZ (Theory of Inventive Problem Solving) tools, as well as a range of mathematical optimization methods, for generating rational design solutions in the development of remotely operated underwater vehicles (ROVs). The analysis and the presented examples demonstrated that the TRIZ methodological framework has significant potential for systematizing creative problem-solving and identifying key technical contradictions, thereby substantially improving the quality of design solutions under specialized operational requirements. The demonstration of TRIZ application in specific ROV development scenarios convincingly shows the feasibility of integrating its tools into the existing regulatory and technical framework governing the design of underwater robotic systems. This approach enables a more formalized and justified selection of architectural and structural solutions while maintaining flexibility and adaptability in the design process.

As part of the validation of the proposed methodological approach, engineering calculations were performed, and recommendations were developed for the layout of an ROV intended for the inspection of offshore oil and gas facilities. The designed configurations of the propulsion system, thruster arrangement, and power supply subsystem demonstrate optimal performance in terms of energy efficiency, maneuverability, and operational reliability. The results confirm that the combination of TRIZ and optimization methods enables a justified selection of the vehicle's technical parameters and enhances its functional capabilities in complex offshore infrastructure environments.

The results obtained in the study confirm the universality, practical value, and relevance of TRIZ principles in addressing modern design challenges for complex technical systems. In particular, it has been shown that the use of TRIZ contributes to increased efficiency in the development of ROVs intended for the diagnosis and monitoring of offshore oil and gas facilities, making this approach a promising tool for the further advancement of underwater robotics.

At the same time, the application of TRIZ in combination with multi-criteria optimization methods has both advantages and certain limitations. Key benefits of the proposed approach include structuring the engineering search process, formalizing the identification of technical contradictions, and enabling targeted solutions beyond traditional compromise limits defined by the Pareto front. This is especially important when designing specialized ROVs operating under non-standard and demanding conditions of offshore oil and gas infrastructure.

Among the limitations of the method is the subjective nature of assigning criterion weights when forming

the integrated utility function. Weight values are generally determined based on expert assessments and client priorities, which can influence the final ranking of solutions. Moreover, the effectiveness of TRIZ largely depends on the designer's qualifications and the accuracy of formulating technical and physical contradictions. These limitations can, however, be partially mitigated through group expert evaluations, sensitivity analysis, and iterative procedures for revising weights and criteria at various stages of the ROV lifecycle. In the future, the presented approach could be expanded by incorporating stochastic optimization and machine learning methods to refine weight coefficients and identify robust design solutions.

Funding: The research manuscript does not receive any outside funding

Author Contributions: conceptualization, review, writing, editing, data collection, calculation conclusion – Pavel Shcherban.

References

- [1] Khojasteh, D., & Kamali, R. (2017). Design and dynamic study of a ROV with application to oil and gas industries of Persian Gulf. *Ocean Engineering*, 136, 18-30. DOI: 10.1016/j.oceaneng.2017.03.014
- [2] Ryu, J., Nam, K., & Ha, K. (2020). A Basic Study of ROV System Design for Underwater Structure Inspection. *Journal of the Korean Society of Industry Convergence*, 23(3), 463-471. DOI: 10.21289/KSIC.2020.23.3.463
- [3] García-Valdovinos, L. G., Salgado-Jiménez, T., Bandala-Sánchez, M., Nava-Balazar, L., Hernández-Alvarado, R., & Cruz-Ledesma, J. A. (2014). Modelling, design and robust control of a remotely operated underwater vehicle. *International Journal of Advanced Robotic Systems*, 11(1), 1. DOI: 10.5772/56810
- [4] Salgado-Jimenez, T., Gonzalez-Lopez, J. L., Pedraza-Ortega, J. C., García-Valdovinos, L. G., Martínez-Soto, L. F., & Resendiz-Gonzalez, P. A. (2010, October). Design of ROVs for the Mexican power and oil industries. In 2010 1st International Conference on Applied Robotics for the Power Industry (pp. 1-8). IEEE.
- [5] Said, M. F. M., Roslan, I. S., & Bakar, S. A. (2015). Conceptual design of remotely operated underwater vehicle. *Journal of Transport System Engineering*, 2(1), 15-19.
- [6] Shcherban, P. S., Survey of reliability of offshore oil and gas infrastructure in South Baltic conditions / P. S. Shcherban, E. Mazur. *Pomorstvo* (2022), Vol. 36, No. 1, pp. 68-73. DOI 10.31217/p.36.1.8.-EDN NIYNHL.
- [7] Jing, Q., Luo, J., & Li, Y. (2021, June). A new modular intensive design solution for ROVs. In *International Conference on Applied Human Factors and Ergonomics* (pp. 69-76). Cham: Springer International Publishing.
- [8] Nitonye, S., Adumene, S., Orji, C. U., & Effiong Udo, A. (2021). Operational failure assessment of Remotely Operated Vehicle (ROV) in harsh offshore environments. *Pomorstvo*, 35(2), 285-296.

- [9] Shah, S. I. A., Khan, M., & Ahmad, S. M. (2021, October). Design, development, and fabrication of a low cost remotely operated unmanned underwater vehicle. In 2021 International Conference on Robotics and Automation in Industry (ICRAI) (pp. 1-5). IEEE. DOI: 10.1109/ICRAI54018.2021.9651355
- [10] Graczyk, T. (1999). Methodology of remotely operated vehicle design. *WIT Transactions on The Built Environment*, 45.
- [11] Bashirov, R. J., Abdullayev, O. M., & Abdullayev, R. O. (2025). The System Analysis and Mathematical Model of the Subsea Construction Vessels. *Herald of Azerbaijan Engineering Academy*, 17(2), 73-82.
- [12] Thieme, C., Grøtli, E. I., Kråkenes, T., Winge, S., Transeth, A. A., & Authority, N. O. I. (2025). Study of the Advantages and Disadvantages of Shore-Based ROV Inspections and Operations on Subsea Facilities.
- [13] Restrepo-Carmona, J. A., Taborda, E. A., Paniagua-García, E., Escobar, C. A., Sierra-Pérez, J., & Vásquez, R. E. (2024). On the Integration of Complex Systems Engineering and Industry 4.0 Technologies for the Conceptual Design of Robotic Systems. *Machines*, 12(9), 625.
- [14] Wegner, D. C., Omine, V., & Ibochi, A. (2024). The Role of Remote Operated Vehicles (ROVs) in Offshore Renewable and Oil & Gas Asset Integrity.
- [15] Altshuller, G. (2002). 40 principles: TRIZ keys to technical innovation (Vol. 1). Technical Innovation Center, Inc..
- [16] Ibrahimov, B. (2021). Intelligent inspection robotics: an open innovation project. *AI & SOCIETY*, 36(3), 1011-1020.
- [17] Kang, Y. J. (2009). The study on new product designing method by using TRIZ (No. 2009-01-0988). SAE Technical Paper.
- [18] Cavallucci, D. (2002). TRIZ, the Altshullerian approach to solving innovation problems. In *Engineering design synthesis: understanding, approaches and tools* (pp. 131-149). London: Springer London.
- [19] Altshuller G. TRIZ (2013). *Design Problem Solving with Systematic Innovation*.
- [20] Ghane, M., Ang, M. C., Cavallucci, D., Kadir, R. A., Ng, K. W., & Sorooshian, S. (2024). Semantic TRIZ feasibility in technology development, innovation, and production: A systematic review. *Heliyon*, 10(1).
- [21] Bukhman, I., & Bukhman, I. (2021). The Ideas of TRIZ. *Technology for Innovation: How to Create New Systems, Develop Existing Systems and Solve Related Problems*, 1-9. DOI: 10.1007/978-981-16-1041-7
- [22] Malvik, T. O. (2025). TRIZ as an innovation tool for opportunity management and Lean Construction. *Procedia Computer Science*, 256, pp. 1459-1466.
- [23] Tsurkan, K. A. Application of autonomous and remotely operated underwater robots in the oil and gas industry / K. A. Tsurkan, N. V. Aksenova // *Recent Achievements and Prospects of Innovations and Technologies.-2025.-No. 4.-P. 340-347.-EDN WDAQBIZ*.
- [24] Rocha, F., & De Tomi, G. (2015, October). Basic mapping of the inspection process in offshore oil production facilities. In *OCEANS 2015-MTS/IEEE Washington* (pp. 1-8). IEEE.
- [25] Fun Sang Cepeda, M., Freitas Machado, M. D. S., Sousa Barbosa, F. H., Santana Souza Moreira, D., Legaz Almansa, M. J., Lourenço de Souza, M. I., & Caprace, J. D. (2023). Exploring autonomous and remotely operated vehicles in offshore structure inspections. *Journal of Marine Science and Engineering*, 11(11), 2172.