European Maritime Safety Agency

RBAT Part 3
Method development

Summary of the modification to the Risk-Based Assessment Tool (RBAT) Methodology

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EMSA

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List of Abbreviations

Abbreviation	Full term
ConOps	Concept of Operations
FDIR	Fault Detection, Isolation and Recovery
IMO	International Maritime Organization
MASS	Maritime Autonomous Surface Ships
NMA	Norwegian Maritime Authority
RBAT	Risk Based Assessment Tool

1. INTRODUCTION

1.1 Background

EMSA has contracted DNV to perform a functional study to develop a Risk-Based Assessment Tool (RBAT) for Maritime Autonomous Surface Ships (MASS) concepts. The study involved developing a methodological framework and a software assessment tool to support the process of carrying out an assessment following this methodology. The purpose of the RBAT methodology is to assess whether increased or new ways of using automation and remote operation are as safe or safer than conventional shipping.

As outlined in DNV's proposal (DNV, 2020) and EMSA's Tender Specifications (EMSA, 2020), the RBAT study consists of three parts:

- Part 1: Develop a framework for a generic MASS risk assessment tool.
- Part 2: Test the risk assessment tool on specific cases and develop a software tool prototype.
- Part 3: Re-iterate testing on more complex cases and finalise the software tool.

The main deliverables developed as a part of the study is as follows:

Number	Title	Issued
Part 1		
1st Report	Framework for generic risk assessment tool for MASS concepts (Report 1 of 2)	2020-12-18
2nd Report	Framework for generic risk assessment tool for MASS concepts (Report 2 of 2)	2021-06-22
Part 2		
3rd Report	Specific MASS concepts & risk evaluation technique proposed for testing the RBAT	2021-05-06
4th Report	Testing of RBAT on specific cases of MASS concepts	2022-09-26
Part 3		
5th Interim Report	Testing of RBAT on specific cases of MASS concepts - Interim report	2023-07-04
5th (2nd Interim) Report	Testing of the Risk-Based Assessment Tool (RBAT) on specific cases of MASS concepts and development of the RBAT software – second interim report	2023-12-18
6th Report	Final Method description and guide to the web-based Risk-Based Assessment Tool (RBAT) software solution	2024-12-16
RBAT method description	The Risk-Based Assessment Tool (RBAT) method description	2025-04-25

Table 1-1 Overview of deliverables in the RBAT project under the framework contract number 2020/EMSA/OP/10/2020.

The current report summarises the main work related to the RBAT method development as outlined in deliverables developed as part of the RBAT Part 3 project (listed above).

2. The web-based RBAT software solution

2.1 Short Description of the RBAT tool

The RBAT tool is intended for organisations to support them in risk assessing of a MASS concept or reviewing an existing risk assessment in the tool. The user can hence be Maritime Authorities, Shipping companies, system developers and other organisations involved in the development of MASS. Each stakeholder can have their organisation registered to use the tool, upon request to an EU member state or to EMSA directly.

The tool supports the registration of different types of user roles, including administrative users and regular RBAT users. Within the tool, registered users from other organisations can be invited to contribute to a created risk assessment, or to review it. Information about the development of the RBAT tool is not further described in this version of the report.

3. Strengths of RBAT method and tool

The 5th Report highlighted several preliminary benefits of the RBAT method. These are further elaborated below, demonstrating the strengths of the method in addressing the unique challenges of MASS concepts.

3.2 RBAT is a function-based system theoretical approach tailored for risk assessing MASS concepts

RBAT is a function-based, system theoretical framework, which focuses on automated or remotely operated function central to MASS concepts. The method systematically addresses the core of what is "novel" about automated/remotely operated vessels, i.e. risks emerging when allocating functions from vessel to land and from human to system. This approach offers several benefits:

- Improves awareness about control related risks.
- Addresses risks that may not be addressed in a conventional HAZID-workshop.
- Analyses hazard causes that are essential for autonomous and remotely operated systems. Particularly systematic failures and human errors (by systematically considering how humans are still part of the control loop, and their new responsibilities and tasks they are given, e.g. supervisory tasks).

RBAT is the only method tailored specifically for the risk analysis of autonomous and remotely operated vessels.

3.3 RBAT can be used as a tool to effectively mature the MASS concept and support the development process by generating design requirements

RBAT's flexibility makes it a valuable tool for maturing MASS concepts and supports the development process by generating design requirements. Its adaptability allows for application across different functions and levels of abstraction, making it relevant at different phases of a MASS concept's development:

- Early-phase risk assessment: Facilitates preliminary risk assessment in the early stages of the concept development (focusing on the first module of the scenario analysis, i.e., **Error! Reference source not found.** a nd **Error! Reference source not found.**).
- Concurrent development: Enables iterative updates and adjustments to both the risk assessment and the ConOps, allowing them to mature together throughout the development process:
- Alignment with Risk-based Design: Complements risk-based design by conducting hazard analyses, guiding the development of safety and design philosophies, and validating the adequacy of these philosophies in final designs (e.g., redundancy, independence)

Additionally, the RBAT tool enhances transparency and traceability in risk assessments.

3.3.1 RBAT provide details for what needs to be included in a ConOps document

When setting up the configuration in the RBAT tool (or in MS Excel prior to an RBAT assessment), the user will need to use input from a ConOps-document. A ConOps is a document that is required by all classification societies, maritime administrations and assumably the MASS Code. If this information is not provided in the ConOps, RBAT can be used to identify and created necessary configurations (e.g., *Function Tree, Mission phases, Operational Restriction, Performing Agents,* etc) at the beginning of the risk assessment. At the later stages in the risk assessment, RBAT can for example identify fallback functions/states, something which is also required to be documented in a ConOps-document.
RBAT can be used both to define the Operational Envelope limits, while at the same time testing whether the limits are set correctly (by reviewing the operational restrictions and enabling conditions).

3.3.2 Systematic evaluation of fallback functions and other mitigation measures

RBAT systematically evaluates whether fallback functions, fallback states and other mitigations are sufficient to operate within the intended safety and operational parameters, something which is required by DNV Class Guideline 0264, NMA and assumably mentioned in the IMO MASS Code. The method will also identify which systems are critical for the availability of fallback states, which is required by some maritime administrators (e.g., NMA) for instance.

3.4 RBAT does not need probabilistic estimates of frequencies or likelihood of failures

During the development of RBAT, experts concluded that probabilistic approaches are unsuitable for systematic failure events. Such events are the consequence of inadequate work processes and may be introduced at all stages in the system lifecycle. Some examples are incomplete risk analysis, inadequate development of barrier strategies, incomplete requirement specifications, weaknesses in software design, programming errors, quality problems in hardware production, and inadequate planning of maintenance. It is difficult to quantify the probability of systematic failure events as they typically will be present in a system from day one, or introduced through modification, but be hidden until specific circumstances occur.

To address this, RBAT shifts focus from likelihood estimation to event mitigation, emphasising how well a system can recover from or prevent adverse outcomes. in RBAT, the level of risk for each scenario analysed is determined based on these three factors.

- Exposure to enabling conditions: Identifying scenarios where risks might materialize.
- Strength of the available mitigations: Assessing the effectiveness and robustness of measures to prevent or manage failures.
- Severity of the worst-case outcome: Determining the potential impact of catastrophic events without relying on statistical data.

3.5 RBAT provides generic function trees and mission phases

RBAT significantly reduces the time and effort required for risk assessment by providing pre-established generic function- and mission trees. Experience from real-life projects has demonstrated that this serves as an effective starting point for project specific adaptions, eliminating the to build function lists from scratch. Key advantages include:

- Pre-Built Frameworks: Users can select and customize functions and control actions from any level of the generic function- and mission tree.
- Reusable models: Mission models and function trees can be saved and reused across different concepts, as detailed in the user guide to the RBAT tool.

3.6 Documentation from RBAT as a key strength

The results of the RBAT process typically include several key deliverables that guide risk control and management efforts, making the documentation itself a significant strength:

- Operational Restrictions: These represent a set of safety requirements derived from the analysis, such as limiting operations during adverse weather or restricting speeds in high-traffic areas.
- Qualified Mitigating Measures: The analysis identifies and qualifies mitigating measures, which also form a significant source of safety requirements. While some measures may have been included in the Concept of Operations (ConOps), RBAT often identifies additional measures needed to address specific risks.
- Assumptions: Any assumptions made during the analysis must also be documented and treated as safety requirements. This is crucial because invalid assumptions, may compromise the effectiveness of associated mitigating measures.
- Action Items: The action list in a real-world project tracks various items, including candidate risk controls that have not yet been credited. These action items typically reflect opportunities for further risk reduction and should be revisited periodically to explore their feasibility.

4. Summary of the method evolution from the 3rd report until the last version of the method description (in the 6th report)

The 3rd Report (submitted in May 2021) included an outline of a step-by-step guidance to the RBAT methodology, consisting of the five main parts that we recognise in the current method description. This first approach consisted of five main high-level parts with a total of 15 steps. In the 4th Report, these where increased to 20 steps. While the in the first 5th interim Report there are 21 steps, while in the 2nd interim report there are 19 steps.

The five high level parts has been the same throughout the method development:

1. Describe Use of Automation
2. Perform Hazard Analysis
3. Perform Mitigation Analysis
4. Perform Risk Evaluation
5. Address Risk Control

The main updates and developments to each of the method descriptions presented in the four last reports are summaries in the following sections.

4.2 Updates to the framework described in the 3rd Report

While the focus in the 3rd report was on defining MASS Concepts, control functions and initial hazard identification, the method description in the 4th report presented tables and examples providing more context. The 4th Report introduced three ConOps for testing the methodology, and the method was updated based on the experience of applying the method on these concepts. One of the main updates to the method was improved clarity on mitigation effectiveness and operational restrictions. A complete overview of the updates made to the RBAT method is described in table 21 in the 4th Report.

4.3 Updates to the framework described in the 4th Report

The 1st and 2nd interim 5th Reports included a consolidated update of the framework. These updates were based on:

- **Test cases** described in the Interim 5th Report (ConOps A and B, originally introduced in the 3rd Report).
- **Development of a detailed specification for the RBAT software tool**, which led to a shift from using MS Excel to an online database solution. This change influenced the sequence in which steps in the method are applied. Additionally, the database's ability to manage many-to-many relationships introduced new possibilities not feasible in Excel. This process also revealed that some of the earlier terminology in the methodology had become outdated and needed revision.
- **Practical experience from applying RBAT** across all vessel functions in ongoing real-world projects, which provided valuable feedback on the method's effectiveness and usability.
- **Planned updates** stemming from earlier work, such as refinements to the definition of key terms.

This resulted in numerous minor updates to the methodology, as well as a few more substantial changes. The latter are detailed in the subsections below.

4.3.1 Part 1 Describe use of automation (and remote control)

There were only a few changes made to Steps 1, 2, and 3. However, it was clarified that most functions were used across multiple operations and mission phases, which had implications for how the hazard analysis was carried out.

In Step 2, a requirement was added to include a project-specific description for all functions. Additionally, Step 3 was updated to include an example of how to describe a performing agent.

The previous Step 4, which involved identifying supervisory agents, was moved to the mitigation analysis section—where this information was actually applied. As a result, the total number of steps in the method was reduced.

4.3.2 Part 2 Performance of Hazard Identification

Step 5 included the following updates:

- A requirement was added to create an ID/Name for each scenario.
- Additional guidelines were introduced for developing distinct scenarios based on different guidewords, causes, mission phases, etc.
- An example was included to illustrate how unsafe conditions were limited to the function being analysed.
- Guidance for the guidewords “Not followed/Rejected” and “Incorrectly provided control actions” was improved.
- Step 6 did not undergo any major changes since the previous report.

Step 7, which addressed enabling conditions, was moved to occur before the determination of worst-case conditions and severity—resulting in a change to its step number. Text was added to clarify that the selection of mission phase/operation for each scenario was to be performed during this step, based on a prediction of where worst-case conditions were likely to occur. It was also clarified that Steps 6–9 needed to be performed iteratively, and that multiple scenarios might be required for the same unsafe condition in order to evaluate which combinations of unsafe condition, mission phase/operation, and accident type represented the highest risk.

Step 8, concerning operational restrictions, was only slightly revised to clarify the use of assumptions. However, like Step 7, it was moved to precede the determination of worst-case conditions and severity, resulting in a change to its step number.

Steps 9 and 10 remained unchanged, apart from their updated step numbers as explained above

4.3.3 Part 3 Perform mitigation analysis

Experience from testing and real-life projects showed that this was the most challenging part of the RBAT process. As a result, significant additional guidance was added. Additionally, the term *mitigation layer* was replaced with *mitigation measure*.

The introduction section remained unchanged, except for updates to step references and the removal of an explicit reference to FDIR in the second bullet list.

- Step 11, which addressed FDIR, remained largely unchanged, except for the addition of a provision allowing assumptions about FDIR not yet documented in the ConOps. (See also Step 19.)
- Step 12, which dealt with the nomination of independent mitigation measures, was expanded and divided into several subsections:
  - *Information required per mitigation* included a table specifying the required content for each mitigation measure.
  - *Identify supervisory control agents for each mitigating measure*, focused on identifying supervisory control agents, was previously part of Step 4. The text was updated to clarify that supervisory agents must be identified for each mitigation measure, rather than for the control action being analysed.
  - *Detection of unsafe conditions,* which was previously a separate step concerning detection and whether a failure would be annunciated or not (from the RCC operator’s perspective), was now incorporated into Step 12. Evaluation of detection capability became part of the process for nominating individual independent mitigation measures, thereby reducing the total number of steps in the method.

A new table was added that identify five generic ways a supervisory agent may detect an unsafe condition has been added. The method now assume that all unsafe conditions may be either annunciated or not annunciated by the performing agents, and consequently nominated mitigation measures must have capability for detection of unsafe conditions even if they are not annunciated by the performing agent. Thus, the user is not selecting annunciated or unannunciated at scenario level anymore.

The 4th Report had a section called "Additional guidance on functionality" related to qualification of mitigating measures. The text was concerned with detection of unsafe conditions and have therefore been moved to *Detection of unsafe conditions* (Step 12) in order to further elaborate on the capability of the detection methods.

Identify relevant operational states after the mitigating measure have been applied was added as a new section providing guidance on identification of operational states.

Step 13 is concerned with qualification of mitigation measures. Here, two new sections were included:

- *Unsafe conditions related to navigation, for which detection is the main challenge* was added to provide guidance on qualification of mitigating measures for scenarios where the vessel is fully controllable but where there are unsafe conditions related to navigation that could lead to collisions or groundings.
- *Choice of Active vs Passive Human Supervision* was added to provide guidance on choice of active vs passive human supervision.

One section was removed from step 13 and included in step 12 as explained above.

For Step 14 which is concerned with evaluating the effectiveness of mitigation layers, additional guidance related to FDIR were added. This was to distinguish between detection of unsafe conditions having causes outside the performing agent and unsafe conditions having causes inside the performing agent.

No changes were made to step 15.

4.3.4 Part 4 Perform risk evaluation

No changes were made to step 16 concerned with determining risk level for the assessed scenario.

In step 17, which is concerned with alternative approaches for determining risk levels, one additional approach which related to mitigation measures that are used frequently also during normal operation was added.

No changes were made to step 18.

4.3.5 Part 5 Address risk control

In Step 19, it was clarified that operational restrictions could also reduce exposure to certain enabling conditions.

It was further clarified that, for risks classified as medium, an evaluation of equivalence to manned ships with a standard-sized crew should be conducted.

A rationale for the risk classification was required for each scenario.

The role of the list of operational restrictions, mitigation measures, and assumptions as a source of safety requirements was clarified, along with a clearer explanation of the roles of assumptions and actions.

4.4 The last updates to the framework described in the 5th Reports

Following the submission of the 1st and 2nd interim Report, additional updates were made to the definitions used in the method framework. These changes were primarily driven by discussions surrounding the IMO MASS Code draft, as well as the ongoing development and testing of the RBAT tool.

Based on feedback and experience gained from applying the method in real-life projects, further guidance was added to the Mitigation Analysis section—specifically under Step 13: *Qualify the Nominated Mitigation Measures.* This mainly included clarifications on how agents could be involved in mitigation measures.

The RBAT Accident Model, included in Appendix E of the method description, was also revised. The updated model incorporated correct terminology (such as f*allback states* and *FDIR*) and clarified that multiple successful mitigation measures could lead to the same degraded/fallback state.

For the method description in the 6th Report, additional revisions were made, though these were of minor significance. The focus was primarily on improving language and clarity, incorporating feedback received from EMSA.

5. References

DNV GL (2020). Proposal for A functional study developing a Risk-Based Assessment Tool for MASS (RBAT MASS). DNV GL doc No: 1-1HPDRGR-M-N-ADSS-1.

EMSA (2020). Invitation to tender No. EMSA/OP/10/2020 for the functional study developing a Risk-Based Assessment Tool for MASS (RBAT MASS).

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