MEGURI 2040
Safety Assessment Seminar
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Presentation 2:
Methods and Concepts for Risk Assessment of Autonomous Ships

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Outline

1. Why risk assessment is needed
2. What to assess
3. How to assess
   - Process overview
   - Preparation
   - Analysis, evaluation, measures, and reassessment
4. Documentation and use of results
   - Certification, functional requirements, and later-stage assessment

→ Based on the MEGURI2040 Stage 1 and Stage 2 safety assessment projects, this presentation outlines key viewpoints and the overall process for safety assessment of future autonomous ship operations.

Why Risk Assessment Is Needed for Autonomous Ships

- Real projects revealed gaps in stakeholder understanding
  - Vague expectations and concerns about “uncrewed ships”
  - A more realistic path: gradual development from operational support

- Risk assessment provides a practical tool for visualising shared understanding and explaining safety

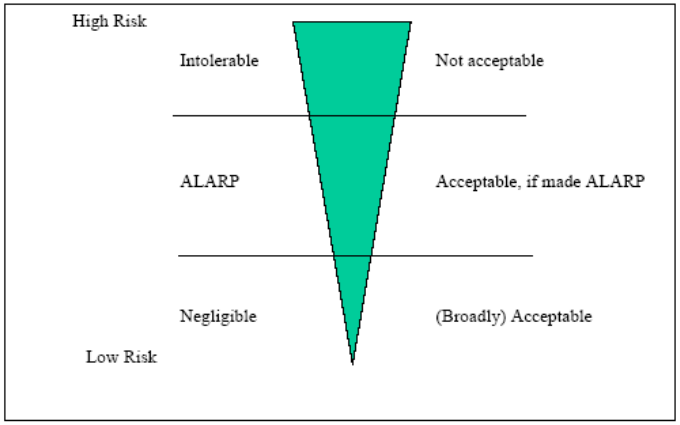
Risk as a Tool for Explaining Safety

- Safety is generally treated as freedom from risk that is not tolerable
  - Not freedom from all risk
- What is risk? → How likely it is that something we want to protect may be lost
  - What do we want to protect?
    - Human life and health
    - Environment
    - Property
  - Risk is often expressed as: Severity × Frequency

References: ISO/IEC Guide 51; IMO FSA Guidelines, MSC-MEPC.2/Circ.12/Rev.2

Risk as a Tool for Explaining Safety

- Assessed risk is judged against acceptance criteria
- IMO FSA uses the ALARP[1] principle to judge risk acceptability and justify additional measures
  - Intolerable
  - ALARP
  - Broadly acceptable
- Equivalent safety may be explained by comparison with conventional ships



ALARP principle (Source: IMO FSA Guidelines, Appendix 5, Fig 2)

- If risk is not broadly acceptable:
  - Intolerable: additional risk reduction is required
  - ALARP: further reduction should be considered

References: ISO 12100 Safety of machinery—General principles for design—Risk assessment and risk reduction; IMO FSA Guidelines: MSC-MEPC.2/Circ.12/Rev.2

[1]ALARP: As Low As Reasonably Practicable

What Should Be Assessed?

- Differences from conventional ships raise safety concerns
- Much of the ship remains unchanged
  - Existing safety measures still apply
- Key differences arise from automation systems, e.g. ANS[1]
  - Added functions: perception, decision-making, and action
  - Changed operations: use, monitoring, and termination
  - New conditions: use, termination, and handover

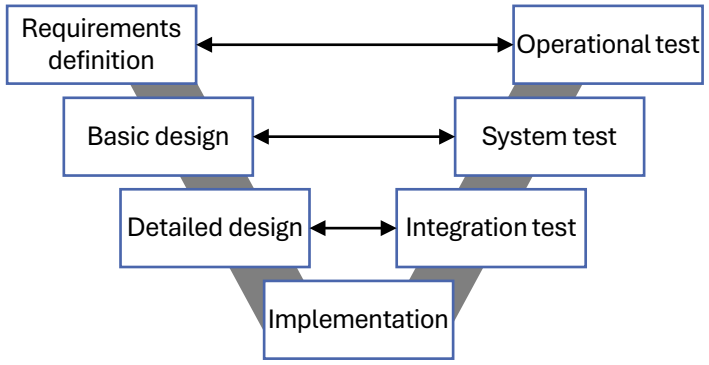
Human–system role allocation changes

- Risk assessment focuses on these new or changed risks

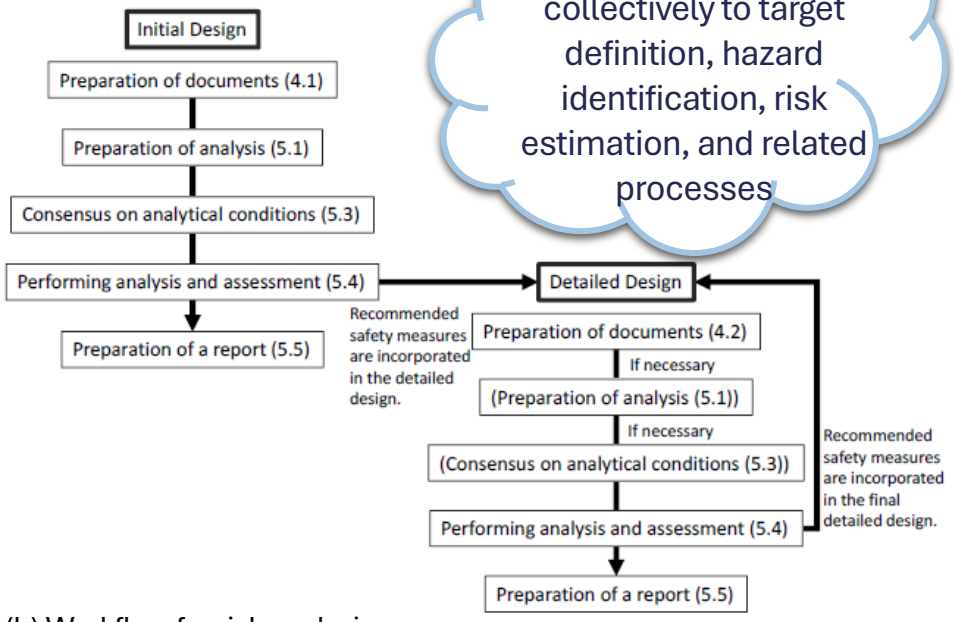
[1]ANS: Autonomous Navigation System; MASS Code, MSC 111/WP.9 Annex 1.

How to Assess: Process Overview

- Safety assessment proceeds in parallel with design and construction
  - Requirements, functions, and role allocation are clarified as design progresses
  - Risk assessment activities are conducted and updated at each design stage



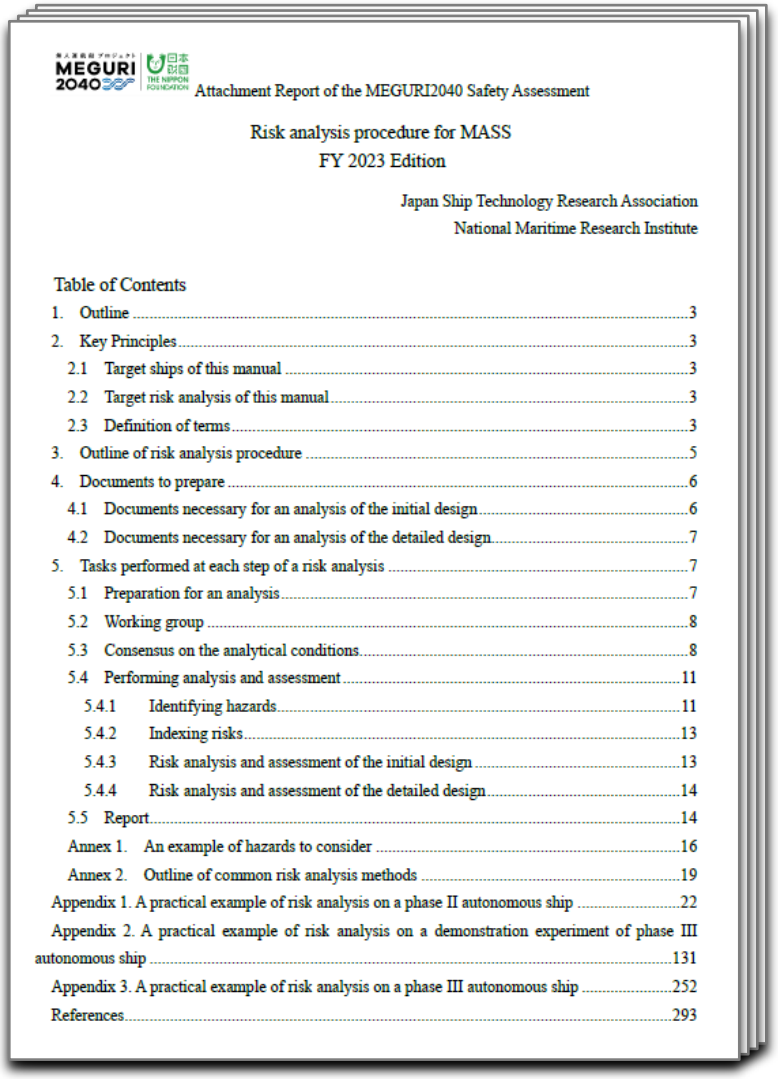
(a) V-model of the development process
(Source: Prepared with reference to IPA, Software Test Estimation Guidebook, Figure 2.1)



(b) Workflow for risk analysis
(Source: Risk analysis procedure for MASS FY 2023 Edition, prepared under MEGURI2040, Figure 3.1)

Risk Analysis Procedure for MASS

- Key points covered:
  - Stepwise application from design to construction
  - Analysis conditions
  - Review team and communication process
  - Analysis and evaluation methods
  - Example documents
  - Publicly shareable examples were prepared based on Stage 1 full-scale ship experience: 2 ship types × 3 operation types
    - Autonomous ship
    - Demonstration trial of an uncrewed ship
    - Uncrewed ship



Attachment Report of the MEGURI2040 Safety Assessment

Risk analysis procedure for MASS
FY 2023 Edition

Japan Ship Technology Research Association
National Maritime Research Institute

Table of Contents

Preparation for Analysis: Defining the Assessment Target

- Specify differences from conventional ships
  - Even the same function may be used differently depending on the goal
  - Clarify the intended operation, required functions, and role allocation

Goal → Functions → Role Allocation → Scenarios → Risk Assessment / measures

Operational methods differ depending on the goal

Reduce steering tasks by following a crew-approved route	Verify functions and safety measures before commercial introduction	Reduce lookout and steering tasks through autonomous offshore navigation
↓	↓	↓
Autonomous ship with crew approval	Demonstration trial of an uncrewed ship	Uncrewed ship with autonomous offshore navigation

Preparation for Analysis: Specifying the ConOps[1]

- Specify and document the intended operation as the Concept of Operations (ConOps[1])
  - How and when ANS is used
  - Interactions among system elements
  - Response outside the ODD

(a) Example of ConOps (Source: Selected excerpts adapted from: Risk analysis procedure for MASS FY 2023 Edition, Appendix 2, Table 1.1.)

● Autonomous navigation methods Autonomous navigation of a ship equipped with this feature is performed by taking over the tasks from the onboard crew on the sea route within the assumed conditions of use and turning on the feature upon having the onboard crew confirming the operation. Completing the autonomous navigation along the sea route within the assumed conditions of use and hanging over the tasks to the onboard crew completes the extent of autonomous navigation. If the ship leaves the ODD during its route, even within the assumed conditions of use, autonomous navigation is stopped by handing over to the onboard crew."
● Means of monitoring relevant feature The sensor information collected and integrated into the present feature, the prepared action plan, and the position of the ship within the ODD are constantly provided to the onboard crew by the dedicated monitoring device on the ship.

	Autonomous ship with crew approval	Uncrewed ship trial	Uncrewed ship: autonomous offshore navigation
Area	Offshore / coastal / remote-island routes	Trial area	Offshore
ANS functions	● Follow the voyage plan ● Plan and manoeuvre according to traffic and conditions		
Human roles	● Crew approve manoeuvring plans	● Shadow personnel monitor and override if needed	● Crew take over when leaving the ODD

[1]ConOps: Concept of Operations (MASS Code, MSC 111/WP.9 Annex 1; Itoh & Matsuoka (2024): Exploring ConOps Prototypes for Initial Risk Assessment of Autonomous Ship Operations, PSAM17&ASRAM2024)

Preparation for Analysis: Conditions and Role Allocation

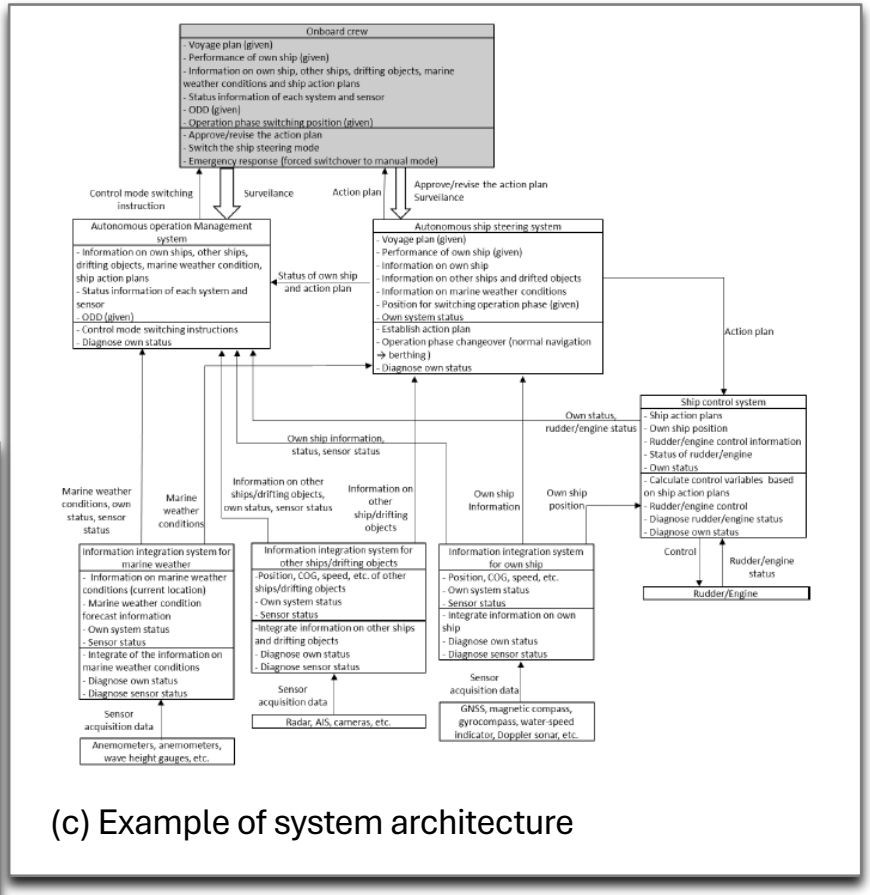
- Organise the functions, operational methods, and conditions needed to realise the ConOps

(a) Example of human–automation role allocation description

Task	Autonomous ship steering system	Information integration system for own ship	Information integration system for other ships/drifting objects	Information integration system for marine weather	Ship control system	Autonomous operation management system	Onboard crew
Switching operation phase	(1) Switching						(2) Surveillance
Obtaining information on own ship		(1) Acquiring and integrating infor-					(2) Surveillance

(b) Example of ODD for the automation system

Marine area conditions	
Navigation zone	Designated ship course
Waters within a departing/arriving harbor	There shall be occupied waters necessary for change of direction in the harbor: 3 L of occupied waters
Waters around a departing/arriving the berth	There shall be occupied waters necessary for departing from or arriving at the berth: 0.5 L of occupied waters
Degree of congestion	Low Congestion: Up to 8 ships within a 3 NM range
Ships not equipped with AIS and obstructions	No non-AIS equipped ships or obstacles that the system cannot detect: No dangerous obstacles of less than 1 m in size within 500 m



(c) Example of system architecture

Source: (a)–(c) Selected excerpts adapted from Risk analysis procedure for MASS FY 2023 Edition under MEGURI2040, Tables 1.4 and 1.6; Appendix 2, Figure 1.1

ODD: Operational Design Domain; MASS Code, MSC 111/WP.9 Annex 1

Agreeing on Analysis Conditions in Advance

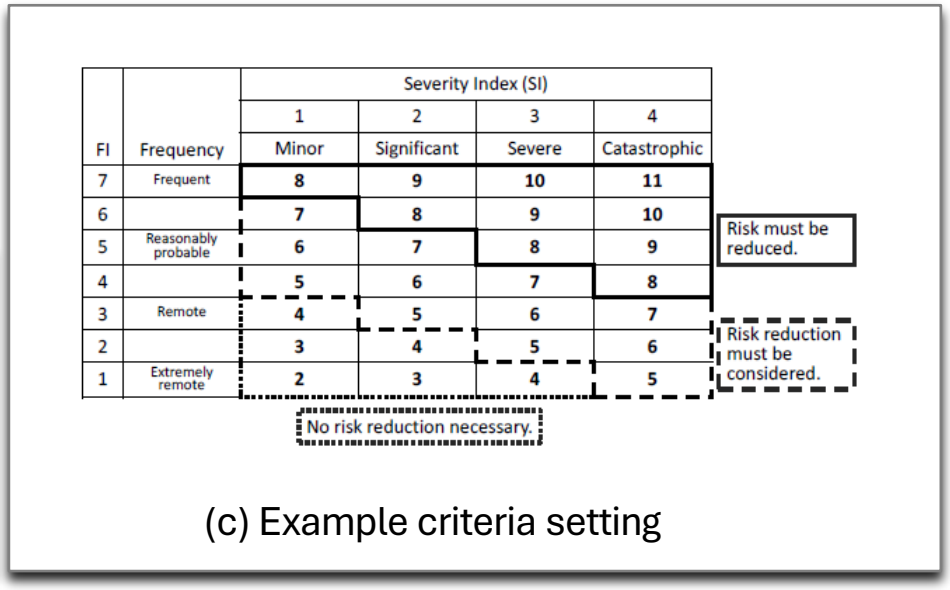
- Harm types: Life, environment, and/or property
- Metrics and criteria: frequency, severity, risk, and Tolerable / ALARP thresholds
- Whether to reassess after risk reduction measures
- Review team: mainly experts on the target system and operation

(a) Example definition of FI.

FI	Frequency	Definition	F (per ship year)
7	Frequent	Likely to occur once per month on one ship	10
5	Reasonably probable	Likely to occur once per year in a fleet of 10 ships	0.1
3	Remote	Likely to occur once per year in a fleet of 1,000 ships	10^{-3}
1	Extremely remote	Likely to occur once in the lifetime of a world fleet of 5,000 ships	10^{-5}

(b) Example definition of SI.

SI	Severity	Effects on human safety	Effects on ship	S (Equivalent fatalities)
1	Minor	Single or minor injuries	Local equipment damage	0.01
2	Significant	Multiple or severe injuries	Non-severe ship damage	0.1
3	Severe	Single fatality or multiple severe injuries	Severe damage	1
4	Catastrophic	Multiple fatalities	Total loss	10



(c) Example criteria setting

Source: (a), (b) Adapted from Risk Analysis Procedure for MASS FY 2023 Edition under MEGURI2040, Tables 5.1–5.2; based on the IMO FSA Guidelines; (c) adapted from Figure 5.1.

Analysis and Evaluation: Identifying What Can Go Wrong

- Identify hazards[1]
  - Define the situation
  - Identify hazards
  - Check causes, consequences, and existing safeguards
- Index risk
  - Frequency and severity of harm
- Whether risk is within the acceptable range

[1]Can be performed using methods such as SWIFT, FMEA, STPA and SMB-HAZID.
Sources: ClassNK Guidelines for Automated/Autonomous Operation on Ships, Ver. 2.1, 2025; Risk analysis procedure for MASS FY 2023 Edition, prepared under MEGURI2040.

Example: Analysis and Evaluation for an Autonomous Ship

Situation
Berthing/unberthing

Hazard
Emergency manual takeover error

Causes
- Mode-switching failure
- Crew unfamiliar with switching
- Distraction / time pressure

Consequences
- Abnormal approach to quay/ships/shallow water
- Collision, grounding, capsizing/sinking

Existing safeguards
- Mode-switching manual
- Crew training

Risk indices
SI = severe → 2
FI = 1/ship-year → 6
RI = 8

Within acceptable range?
RI = 8 → Reduction required

Measures and Reassessment

- If risk reduction is required:
  - Identify additional barriers
  - Reassess risk, considering barrier type and number
- Equivalent safety
  - Compare FI as the main indicator

Example: Analysis and Evaluation for an Autonomous Ship

Additional measure
- Establish crew training method

Reassessment
SI = severe → 2
FI = 1/10 ship-years → 5
RI = 7

Within acceptable range?
RI = 7 → Further reduction should be considered

Sheet ID: 2
Phase: Berthing/unberthing

(a) Example HAZID Worksheet

ID	Hazard	Causes	Consequences	Existing Safeguards	Index (before)							
					SI	FI	RI					
Onboard crew												
73	Emergency manual takeover error	C73.1 Mode-switching failure C73.2 Crew unfamiliar with switching C73.3 Distraction / time pressure	E73.1 Abnormal approach to the berth/ships/shallow water E73.2 Collision, contact, grounding, capsizing, and sinking	• Switching manual • Crew training	2	6	8	Crew training method	2	5	7	Recommendation: manage crew workload and staffing

Key MEGURI2040 issues
- Use conditional estimates for individual scenario frequencies
- Set human error rates based on task characteristics and display/interface design
- Avoid overestimating barrier effects

Source: (a) Simplified and adapted from Risk analysis procedure for MASS FY 2023 Edition, prepared under MEGURI2040, Appendix 2, Table 1.8.

Documentation and Use of Results

Main contents of the report

Target definition

- System definition
- Assumptions
- Concept of operations

Analysis results

- Hazards, causes, and consequences
- Existing safeguards
- SI / FI / RI indices and evaluation
- Additional measures
- Reassessment after measures

Key functions

To functional requirements
e.g. input to goal-based functional requirements in the MASS Code

Information basis for regulatory discussion

Key safeguards

- Relationship between key functions and safeguards
- Validity and transparency of frequency estimates through organised estimation methods
- Items for further confirmation

e.g. simulation-based assessment

Explanatory material for certification

Summary

- In MEGURI2040, we have developed a risk analysis procedure and underlying concepts for systematically conducting risk assessment as part of safety assessment for autonomous ships
- Risk assessment does not simply determine whether a ship is “safe or dangerous”; it systematically identifies and organises the conditions leading to harm, role allocation, scenarios, and risk reduction measures (barriers)
- The results are carried forward to later-stage assessment, such as simulation-based assessment, and also serve as supporting evidence for certification and functional requirements
- The developed risk analysis procedure provides an explainable basis for safety assessment toward social implementation and regulatory development