



### Introduction:

Autonomous underwater vehicles (AUV) are complex electro-mechanical systems which act in a hazardous and unstructured environment. The challenges encountered in this environment are corrosion, rapidly changing current and weather conditions.

The AUR Lab of NTNU operates one REMUS 100 AUV and several other unmanned underwater vehicles, which are exposed to these challenges.

A fault or damage during operation, transport, deployment or retrieval might lead to loss of these vehicles. Risk in this context is the “combination of probability and harm” [1] from these two events.

### Methodology:

The risk assessment and risk management system are based on the ISO 31000 (2009) standard, c.f. figure 1.

#### Risk identification

Preliminary Hazard Analysis (PHA)

#### Risk Analysis

Fault tree analysis (FTA) – focus on damages and planning errors

Event tree analysis (ETA) – focus on damages and planning errors

Fault log evaluation

Human reliability analysis (HRA) – SPAR-H

Expert estimation

### Objective and Scope

Aim of the thesis is to develop a risk management system, adapted to the needs of NTNU's REMUS 100. The system shall provide tools, guidance and reference for future use. The development of the management system is based on current procedures, standards and regulations.

Exemplary and as basis for the risk management, a risk assessment shall be conducted, covering the risk of loss of the AUV and mission abort.

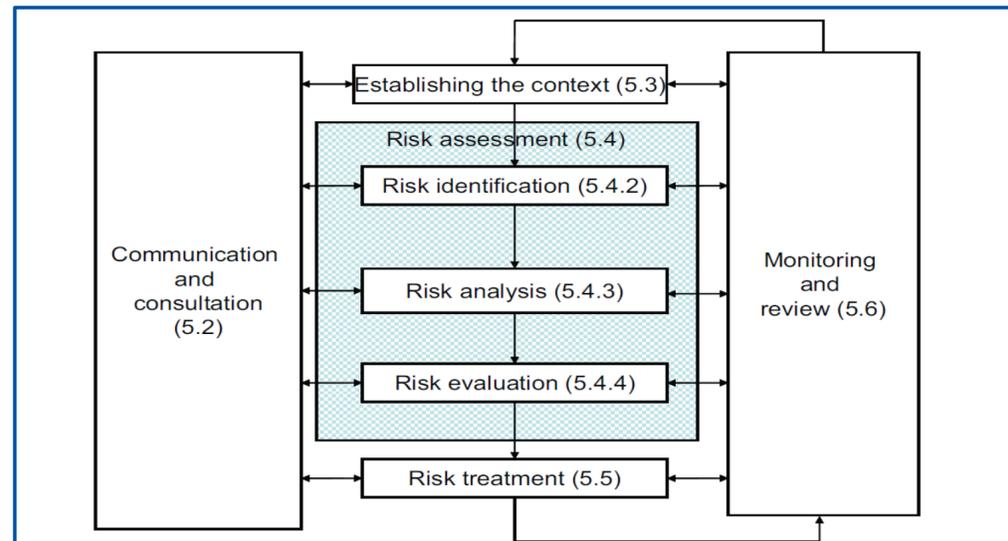


Figure 1: Risk management process described in ISO 31000 (2009)[2]

### Results:

#### Risk Assessment

The current risk of operation was found to be very high. A reassessment with improved procedures, as risk reducing measures, shows a significantly reduced risk, c.f. figure 2. The risk analysis results in a higher risk than expected which is probably overestimated. In 13 missions evaluated, only one was aborted and no significant damages recorded.

#### Risk Framework

Figure 3 summarizes actors, components and links in the risk management system. The main components of the risk management framework are:

- Risk management vocabulary
- Implementation of the system
- Clarification of roles
- Communication and cooperation
- Monitoring and review of risk assessments
- Review of the risk management system
- Risk assessment methodology
- Hazards and risks that should be considered

Further recommendation for use issued:

- Involve and commit all personnel
- Regularly updates
- Save gained experience
- Make it accessible and usable for all users

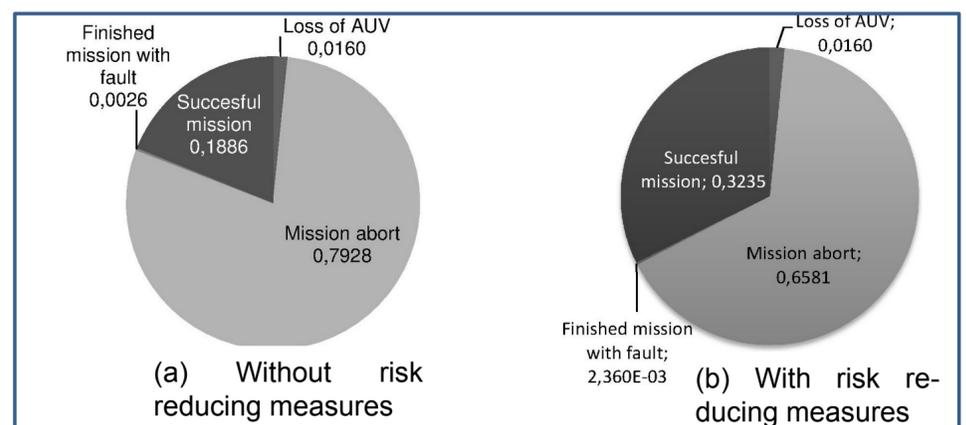


Figure 2: Operational risk; Outcomes and associated probability

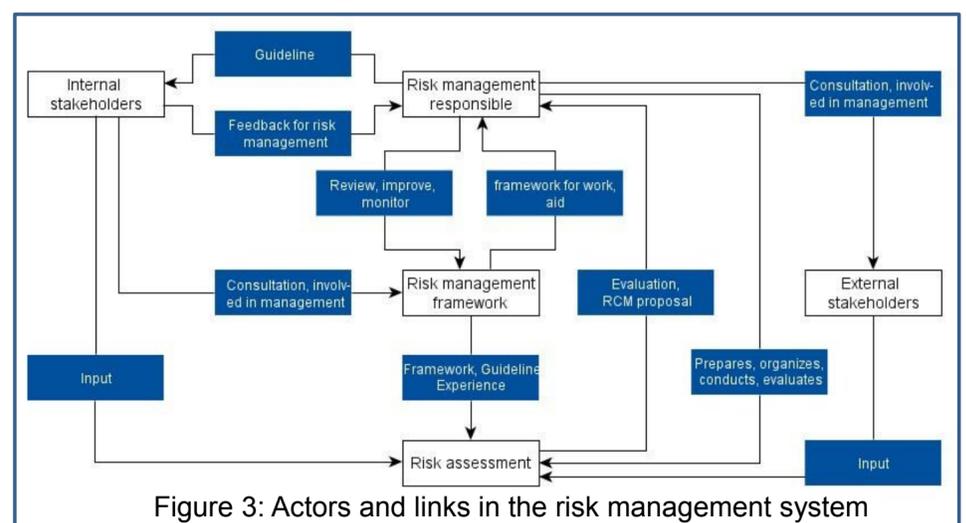


Figure 3: Actors and links in the risk management system

### Conclusion:

The framework is ready for review by the AUR Lab. It is believed that an implemented risk management can help to make operation safer, reduce the probability of loss and improve the efficiency of operation.

The risk analysis looked only in few aspects of risk. It was one of the first modelling risk associated with AUV with HRA. Further risk assessments with different aims might help to identify other risk contributors and consequently eliminate them. Although the total risk presented here seems to be overestimated, it is assumed that the methods were used correctly.

The standard methods PHA, ETA and FTA seem to be applicable. Expert estimation is an appropriate tool for these kinds of assessments, since few statistical data is available. It was found that the SPAR-H method might not be as suitable as was assumed initially. A gain in experience will help to improve handling of methods and simplify the risk management process.

From the results of the risk assessment it can be concluded that in the current operations a need for new or improved procedures exists, which should aim towards maintenance, fault-detection and -solving and mission planning.

### References:

[1] NORZOK Z 013, Risk and Emergency Preparedness Assessment,2010, Lysaker: Standards Norway. [2] ISO 31000 Risk Management: Principles and Guidelines,2009, Geneva: International Organization for Standardization.