2013-2022

NTNU Centre for Autonomous Marine Operations and Systems:
- Shipping and digitalization

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Norwegian Centre of Excellence

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AMOS

Content

- Introduction to AMOS
  - Overview
  - Research areas and focus
- Important concepts
  - Autonomy, risk and risk management
- Risk monitoring and risk control
  - High Reliability Management (HRM)
    - ROV vs. DP
  - Reactive vs. deliberative control
- Conclusions

Overview of Centre of Excellence

INTRODUCTION TO AMOS

NTNU AMOS Vision

- Establish a **world-leading research** centre on autonomous marine operations and systems

- Create **fundamental knowledge** through multidisciplinary research

- Provide **cutting-edge interdisciplinary research** to make autonomy a reality for ships and ocean structures, unmanned vehicles and marine operations

NTNU AMOS will contribute to improved international competitiveness of Norwegian industries as well as to safety and protection of the marine environment

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Next step in research, education and innovation

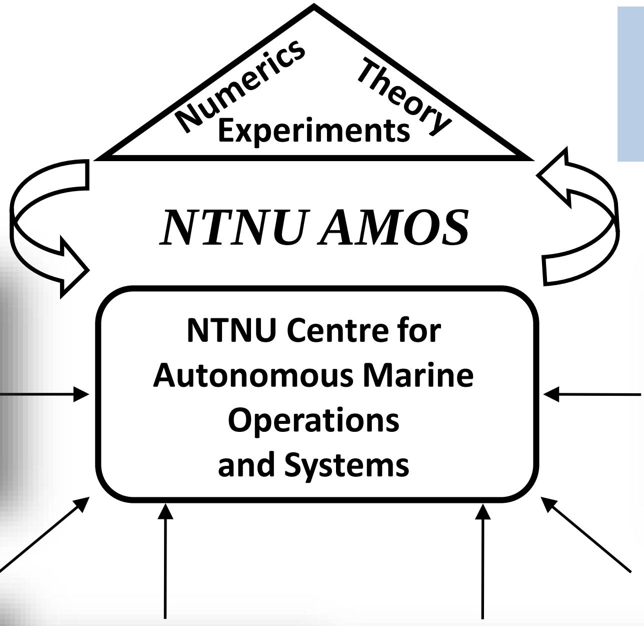
Knowledge fields & research methods

Hydrodynamics and Structural Mechanics

Guidance, Navigation and Control

Marine Biology and Oceanography

Autonomy: Big Data Cybernetics, Sensor Fusion, Computer Vision, Artificial Intelligence, Optimization



NTNU AMOS

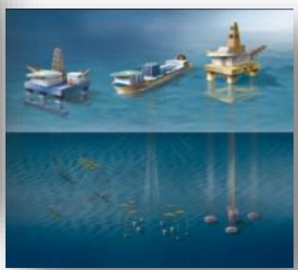
NTNU Centre for Autonomous Marine Operations and Systems

Interdisciplinary research areas & challenges

Greener operations

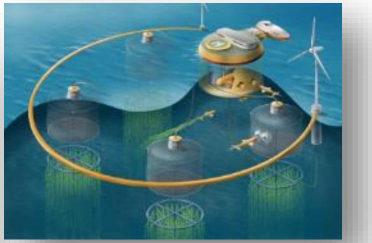
Autonomous surveillance

Offshore renewable energy



Oil & gas in deeper water…

…. and in Arctic areas



Open water biological production

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NTNU AMOS Facts and Figures (Phase 1: 2013-2017)

Personnel by January 2017:
6 Key scientists/professors
2 Scientific advisors/professors
9 Adjunct professors
14 Affiliated professors
13 Post Docs/researchers
84 PhD candidates (on going)
2 administrative staff
2 + lab engineers
3 Spin off companies
36 Educated PhDs
Director: Asgeir J. Sørensen

Partners: The Research Council of Norway, NTNU, Statoil, DNV·GL, SINTEF

International collaborators from: Denmark, Sweden, Portugal, Italy, Croatia, the Netherlands, Estonia, Check Republic, USA, Australia, Brazil, Ukraine, UK, Singapore
National collaborators: University of Tromsø, UNIS, UNIK, Kongsberg Maritime, Rolls-Royce Marine, TechnipFMC, Ecotone, Maritime Robotics, FFI, NGU, Ulstein Group, Eelume, NORUT, Marine Technologies, BluEye, …

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Budget (10 years): 830+ MNOK (~95 MEUR)

Autonomous ships

AMOS’ RESEARCH

Why autonomy?

More intelligent systems that depend less on human operators

Unique (or cheaper) solution when no (or limited) communication is available (bandwidth, remoteness)

Unmanned systems may be smaller, lighter, cheaper and safer to deploy and operate

Qualified operators may be a shortage

Mandatory for new functions

Enables complex functionality; provides fault tolerance and robustness

Enables operations in complex, harsh and remote environment (Dull/Dirty/Dangerous Operations)

Next step towards autonomous operations and systems …..

“Drone ships would be safer, cheaper and less polluting for the $375 billion shipping industry that carries 90 percent of world trade” , Rolls-Royce says

Unmanned cargo ships could become a reality on our oceans within the decade, according to manufacturer Rolls-Royce.

Yara and Kongsberg plan test operation from late 2018 with small crew, located in a modular unit which can be lifted off. Testing with remote control and operation starts in 2019, before the ship in 2020 will set sail autonomously between Porsgrunn, Brevik and Larvik.

The world’s first autonomous passenger ferry between Ravnkloa and Vestre Kanalhavn, Trondheim. Testing starts in 2017, and from 2018 passenger transport will start, if permission is granted from the Maritime Directorate.

http://www.bloomberg.com/news/2014-02-25/rolls-royce-drone-ships-challenge-375-billion-industry-freight.html
https://www.tu.no/artikler/skal-vaere-klar-til-bruk-i-2020-na-testes-verdens-forste-autonome-containerskip/408426
https://www.tu.no/artikler/verdens-forste-forerlose-passasjerferge-kan-ga-over-en-kanal-i-trondheim/363790

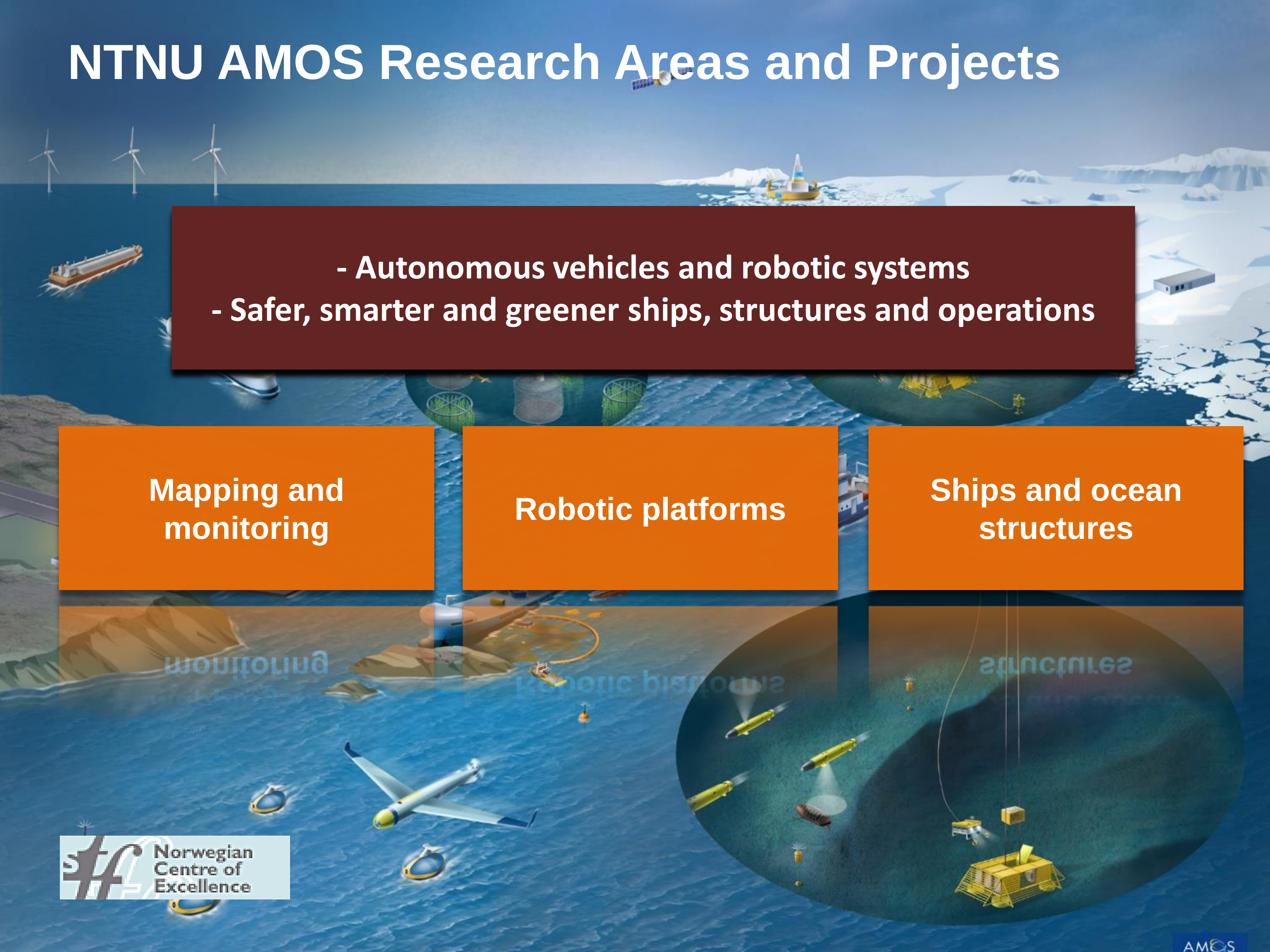
30 September 2016:

Test site opened for autonomous vessels

The Trondheim Fjord in Norway will be the world's first technological playground for pilotless vehicles that move below, on and above the water's surface.

Norwegian authorities, industry, research and universities are behind this.

NTNU AMOS Research Areas and Projects



- Autonomous vehicles and robotic systems
- Safer, smarter and greener ships, structures and operations

Mapping and monitoring

Robotic platforms

Ships and ocean structures

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NTNU AMOS Research Areas

- Autonomous vehicles and robotic systems

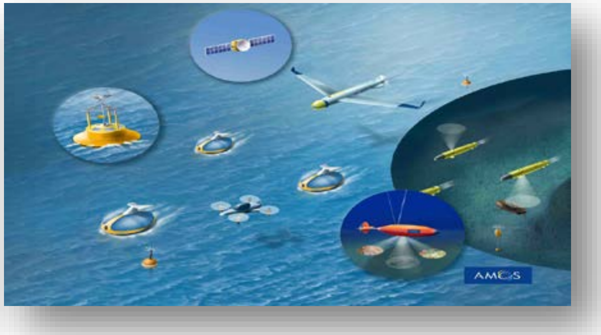
- Safer, smarter and greener ships, structures and operations

Mapping and monitoring

This project considers modelling, mapping and monitoring of the oceans and seabed, and coordinated networked operations; real time processing of payload data, intelligent payload systems and sensor fusion; big data analytics, machine learning, artificial intelligence.

Robotic platforms

This project concerns guidance, navigation and control of unmanned ships, underwater vehicles, aerial vehicles, small-satellite systems; optimization, fault-tolerance, cooperative control, situation awareness; bio-mimics: bio-cyber-hydrodynamics, multi-scale and distributed systems for sensing and actuation.



Ships and ocean structures

This project concerns GNC of autonomous ships; integrated design, monitoring and control of ocean structures – offshore platforms, offshore wind turbines, aquaculture installations, large mega coastal structures; sea state and motion response estimation; hybrid electrical power plants, marine operations in deep waters and harsh environment; consequences of accidental and abnormal events, risk assessment, testing and verification

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NTNU AMOS Research Areas

- Autonomous vehicles and robotic systems
- Safer, smarter and greener ships, structures and operations

Mapping and monitoring

Robotic platforms

Ships and ocean structures

Sensing, navigation, estimation, autonomy

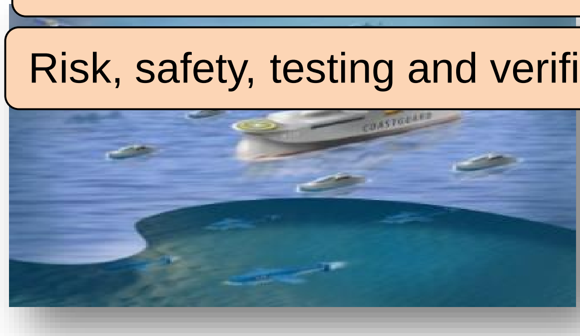
Guidance, control, optimization, autonomy

Hydrodynamics

Structure mechanics

Marine ecosystems and oceanography

Risk, safety, testing and verification



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Safer, smarter and greener

How to design and operate hybrid power plants and propulsion systems on offshore ships using LNG, batteries and diesel engines reducing energy consumption and emissions by a fraction with 70-80% reduction of todays solutions?

How to contribute to standards, rules and regulations by class, authorities and industry that enables the next generation of safer, smarter and greener ships with the next level of autonomy?

How to safely operate at any weather condition, water depth and offshore site with 1/10 of the todays cost?

How to contribute to develop Trondheim's fjord and close by area to be the leading test arena for autonomous marine operations and systems?

New industrial era by Autonomous Unmanned Vehicle Systems

How to develop autonomous sensors and sensors platforms – small satellites, unmanned aerial vehicles, unmanned ships and underwater vehicles, buoys - in air, sea surface and underwater for ocean mapping and monitoring?

How to reduce use of surface vessels with 80% in several offshore oil and gas operations?

How to ramp up mapping and monitoring coverage 10 times with a cost of 1/10?

How to enable public management agencies and industry to pilot and invest in new sensor and technology platforms

AMOS

Important concepts

AUTONOMY AND RISK

Important concepts

- **Autonomy** can be defined as *a system's or sub-system's own ability of integrated sensing, perceiving, analyzing, communicating, planning, decision-making, and acting, to achieve its goals as assigned by its human operator(s) through designed human-machine interface (HMI).*
  - This definition is based on NIST (2008), but adjusted for autonomous systems and operations, both manned and unmanned. This means that unmanned systems is a "sub category" of autonomous systems.

Levels of autonomy (LoA)

LoA	Title	Description	Examples of marine systems and operations
1	Automatic operation (Remote control)	System operates automatically. Human operator directs and controls all functions; some functions are preprogrammed. System states, environmental conditions and sensor data are presented to operator through human-machine-interface (HMI) (human-in-the-loop/human operated).	ROV/ subsea inspection and intervention.
2	Management by consent	System automatically makes recommendations for mission or process actions related to specific functions, where system prompts human operator at important points for information or decisions. At this level, system may have limited communication bandwidth, including time delay due to, e.g., physical remoteness. System can perform many functions independently of human control, when delegated to do so (human-delegated).	DP system, AUV inspection task with support by surface vessel.
3	Semi-autonomous operation or management by exception	System automatically executes mission-related functions when and where response times are too short for human intervention. Human operator may override or change parameters and cancel/redirect actions within defined time lines. Operator´s attention is only brought to exceptions for certain decisions (human-supervisory control).	DP system, energy management systems. AUVs in ocean monitoring and surveillance.
4	Highly autonomous operation	System automatically executes mission- or process-related functions in unstructured environment with capability to plan and re-plan mission or process. Human operator may be informed about progress, but the system is independent and “intelligent” (“human-out-of-the loop”). In manned systems the human operator is in the loop, has a more supervisory role, and may intervene.	AUV in ocean monitoring and surveillance without support of surface vessel. AUVs inspecting subsea installations.

Defining risk

Risk related to an activity:

$$\{\mathrm{e_i}, \mathrm{p_i}, \mathrm{c_i}, \} \qquad (1)$$

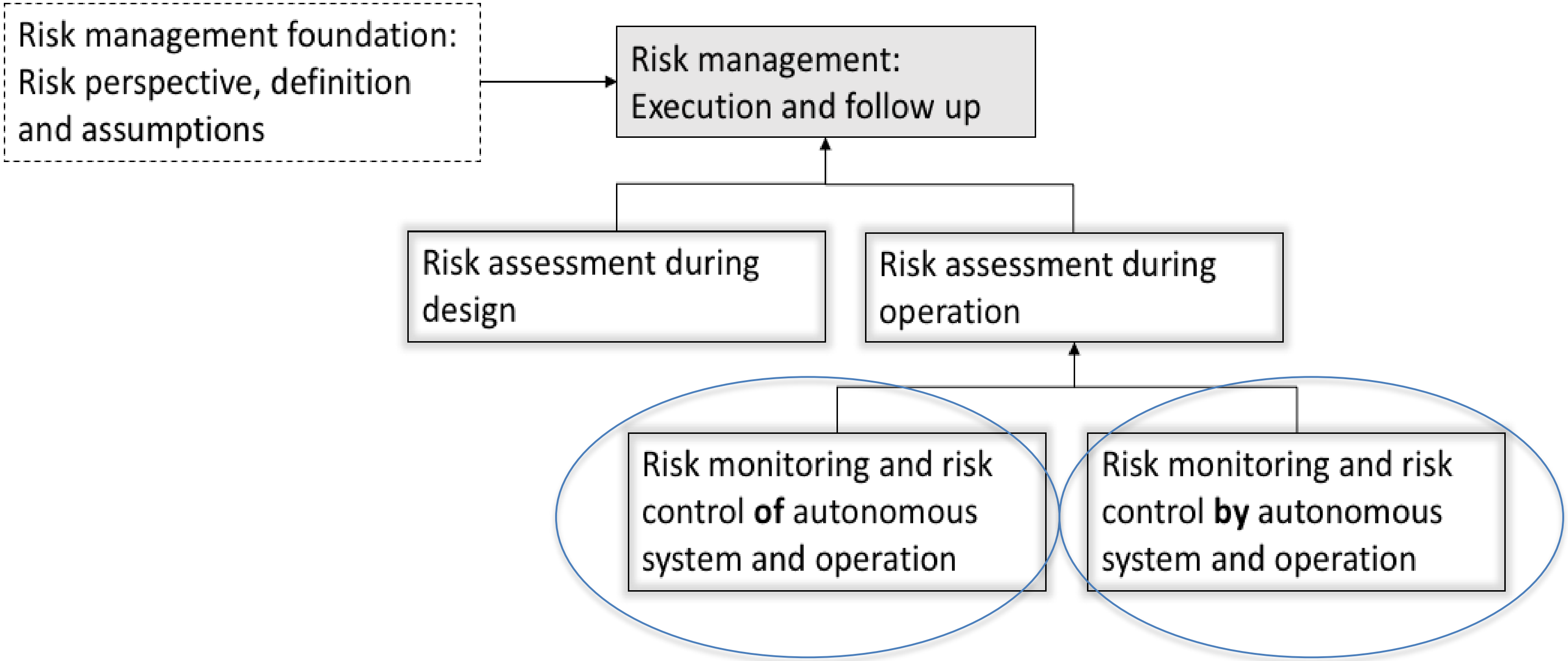
where e_i is a hazardous or undesired event, its various causes and possible consequences c_i, are associated with probabilities p_i. *i* is used as an index to capture all relevant events (Kaplan & Garrick, 1981).

A risk perspective consisting of (i) probability – based thinking, (ii) the knowledge dimension, and (iii) surprises ("black swans"):

$$\{a_i, c_i, q\}|k \qquad (2)$$

where a is a hazardous event, c is the consequence(s) of a, q is a measure of uncertainty, and k is the background knowledge used for determining a, c and q (Aven, 2013).

Risk management and risk control



Risk management foundation: Risk perspective, definition and assumptions

Risk management: Execution and follow up

Risk assessment during design

Risk assessment during operation

Risk monitoring and risk control **of** autonomous system and operation

Risk monitoring and risk control **by** autonomous system and operation

Utne, IB, Sørensen, AJ, Schjølberg, I. 2017. Risk management of autonomous marine systems and operations, OMAE2017-61645

The challenge of high reliability management and safe operator control in autonomous marine systems and operations. Journal article, subm. Sept. 2017.

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Next Generation Inspection Maintenance & Repair (NextGENIMR) 2014-2017

CASE STUDY

Research approach

- Literature studies
- Field work (observations and interviews) onboard Subsea intervention (IMR) vessel in the North Sea during fall 2016
- Case studies
- Incident reports and accident modeling methods

High reliability management (HRM)

- Based on many years of control room operator performance studies at California Independent System Operator (manages high-voltage electricity grid) (Roe & Schulman, 2008; 2016)
- Identifies and describes the challenges and limitations to design and technology when operational exp s are essential to compens ems.
- Underscores why and aged beyond their technology and design if they are to be highly reliable and safe.
- Operators in 4 main performance modes

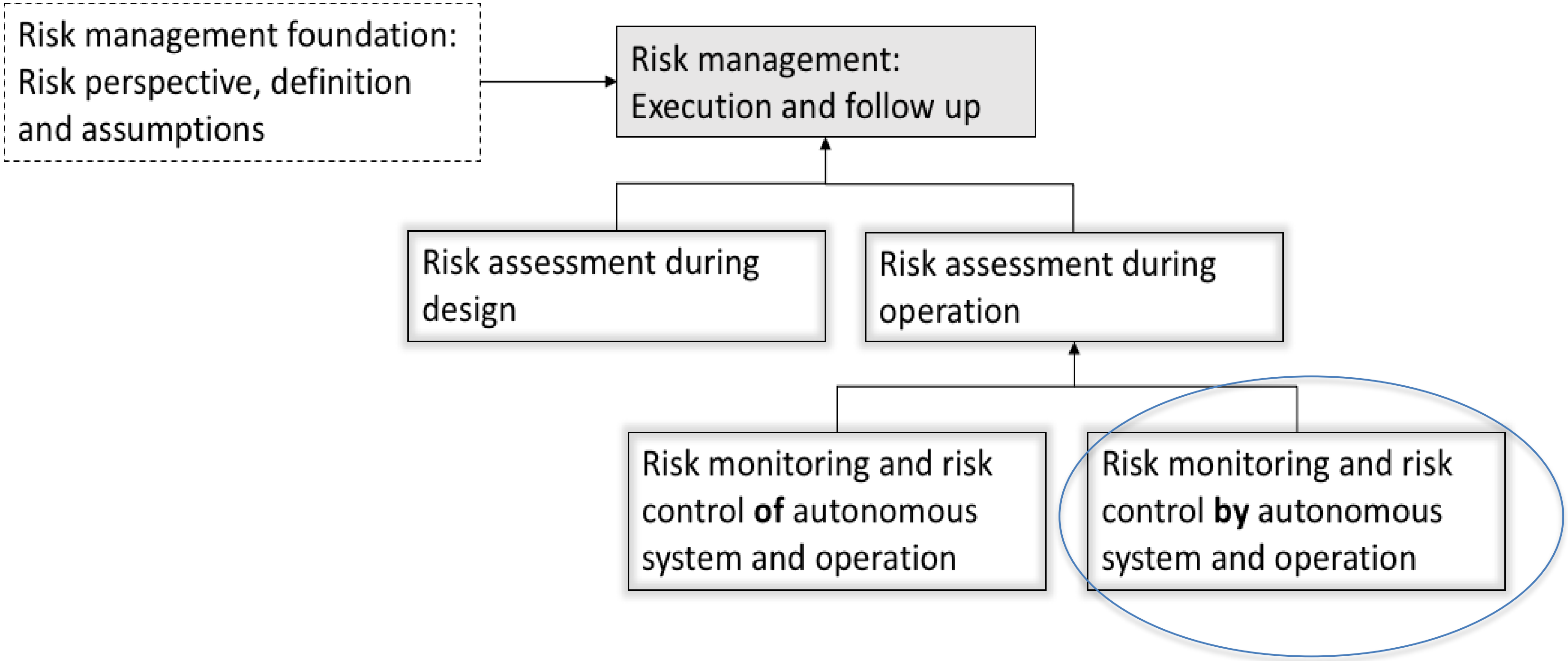
Key insight is that to maintain normal operations the control operators will have to maneuver between performance modes and thus manage very different real-time risks.

		System volatility	
		High	Low
Option variety	High	1. Just in time performance	2. Just in case performance
	Low	3. Just for now performance	4. Just this way performance

Case studies

System/operation	Case study 1 - ROV	Case study 2 - DP
Description	A ROV is a comparatively “simple” system, but it is involved in complex marine operations in demanding environmental conditions. In general, ROVs are operated from a control room onboard a ship or an oil and gas platform/rig.	A DP system has advanced control functionality and enables complex marine operations, such as intervention and drilling. DP systems are operated from the bridge on ships/rigs. The crew on the bridge has to cooperate with the control room.
Stakeholders involved	Client’s onshore planning unit, client’s representative onboard, vessel’s ROV control room operators, crane operator, subsea tooling or specialist sub-contractors, and shift manager.	Client’s onshore planning unit, client’s representative onboard, and vessels’ bridge management team/DP operators.
Main purpose of system/operation	To maintain/ensure high production availability in client’s oil and gas subsea production systems.	To maintain ship position to enable subsea intervention as means for maintaining high availability of subsea production systems.
Autonomy level	LoA 1	LoA 2-3
Operational aspects	Facilitates inspection, maintenance and repair of subsea wells and production systems, including pipelines.	Enables complex marine operations, including subsea intervention.
Normal operation	Has year-round operation. May/may not disrupt oil and gas production during intervention.	Maintains ship position.
Disrupted operation	Mission aborted, but main consequence is extended operation time and increased ship operation cost. If oil/gas production is shut down, high costs for delays incur.	System alarms occur. May lead to aborted mission, but main consequence is extended operation time and increased ship operation cost.
Failed operation	Mission aborted, due to major physical damage to the ROV or subsea production system. The operation cannot be commenced without extensive repairs and onshore support.	Loss of position, i.e., drift off or drive off, with serious consequences, including but not limited to loss of ROVs and collision with rig/platform.

Risk management and risk control



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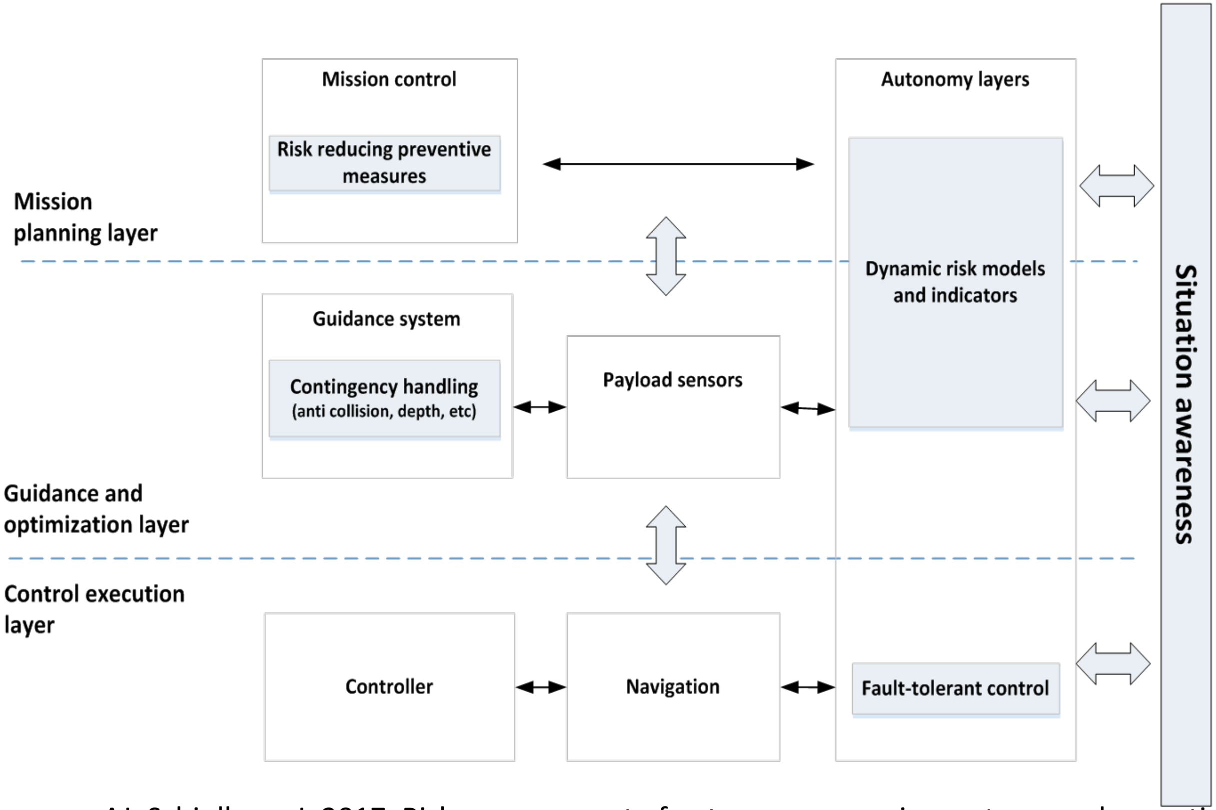

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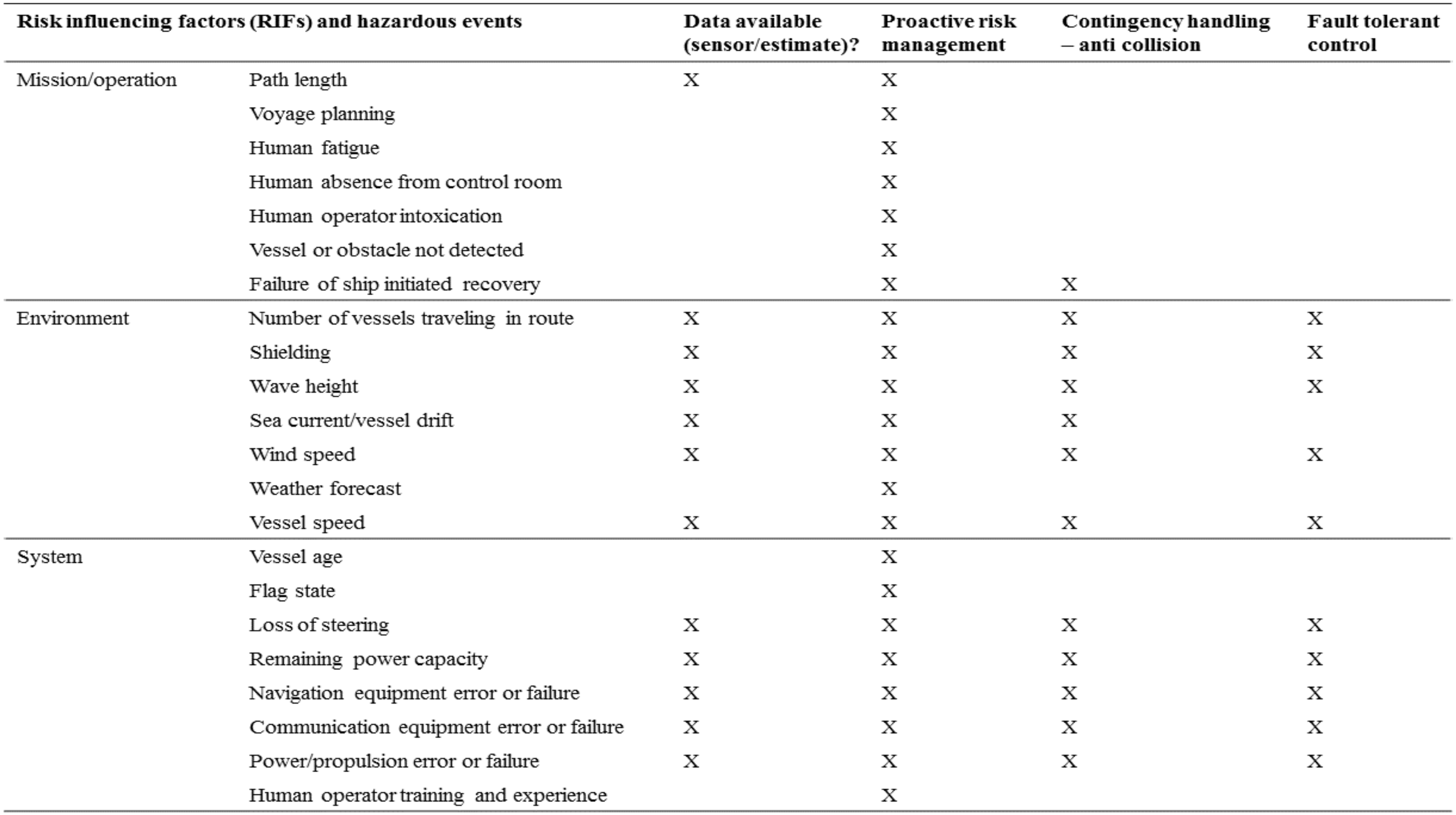
Examples of RIFs and hazardous events impacting collision risk



Risk influencing factors (RIFs) and hazardous events		Data available (sensor/estimate)?	Proactive risk management	Contingency handling – anti collision	Fault tolerant control
Mission/operation	Path length	X	X		
	Voyage planning		X		
	Human fatigue		X		
	Human absence from control room		X		
	Human operator intoxication		X		
	Vessel or obstacle not detected		X		
	Failure of ship initiated recovery		X	X	
Environment	Number of vessels traveling in route	X	X	X	X
	Shielding	X	X	X	X
	Wave height	X	X	X	X
	Sea current/vessel drift	X	X	X	
	Wind speed	X	X	X	X
	Weather forecast		X		
	Vessel speed	X	X	X	X
System	Vessel age		X		
	Flag state		X		
	Loss of steering	X	X	X	X
	Remaining power capacity	X	X	X	X
	Navigation equipment error or failure	X	X	X	X
	Communication equipment error or failure	X	X	X	X
	Power/propulsion error or failure	X	X	X	X
	Human operator training and experience		X		

Utne, IB, Sørensen, AJ, Schjølberg, I. 2017. Risk management of autonomous marine systems and operations, OMAE2017-61645

Conclusions

- The presented foundation for risk management is relevant for different stakeholders of both manned and unmanned systems.
  - Producers of autonomous (marine) systems need to develop an overall strategy for requirements to safety and reliability ensuring that the systems fulfill the requirements.
  - Authorities have to be more proactive when it comes to regulating and follow up of this kind of technology.
- The frequency of human error related to risk of misjudgement may be reduced with higher LoA.
- The risk of complacency associated with the higher LoA can result in operators not revealing early signals of critical deviations in the system.
- Risk models that can provide online decision support subject to environmental and operational conditions and limitations, failure scenarios, consequence classes, both proactively and reactively, for safer operation are needed.

Acknowledgements

Next Generation Subsea Inspection, Maintenance and Repair Operations (NextGenIMR)

NTNU AMOS through the Centres of Excellence.