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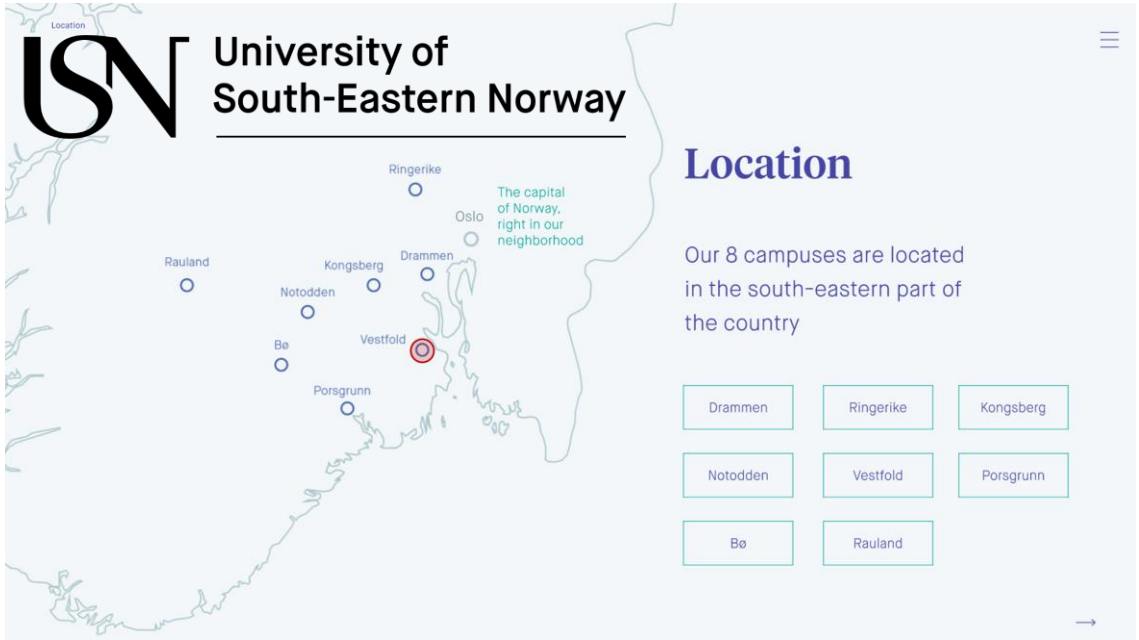
Autonomous Ships



28.11.2020

Associate Professor Hyungju Kim

University of South-Eastern Norway



NTNU
Det skapende universitet



SAMSUNG
HEAVY INDUSTRIES



18.230 STUDENTER

1.900 ANSATTE

BA 65 BACHELOR-UTDANNINGER

MA 36 MASTER-UTDANNINGER

PhD 8 DOKTORGRADS-PROGRAMMER

8 CAMPUSER

BØ – DRAMMEN – KONGSBERG
NOTODDEN – PORSGRUNN
RAULAND – RINGERIKE – VESTFOLD

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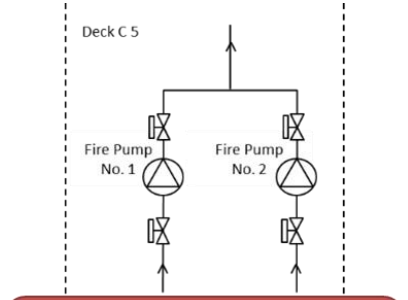
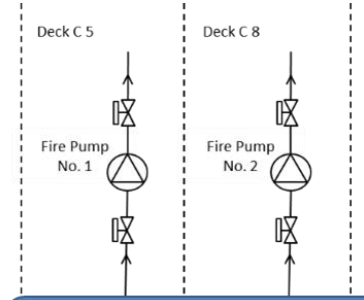
PhD Research

- Maritime Safety

  - An analysis of accident causation and measures for reducing risk at sea

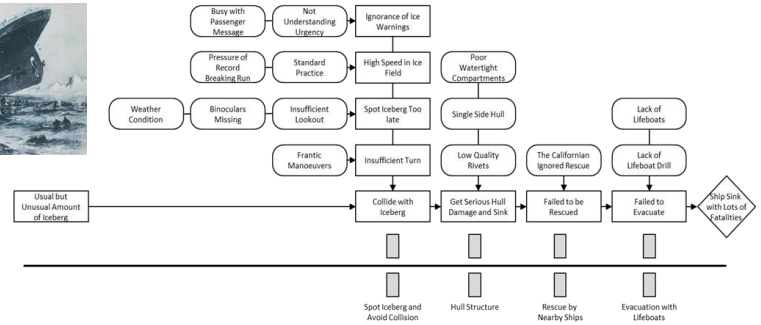


HEF
1.64 x 10^{-5} per ship year

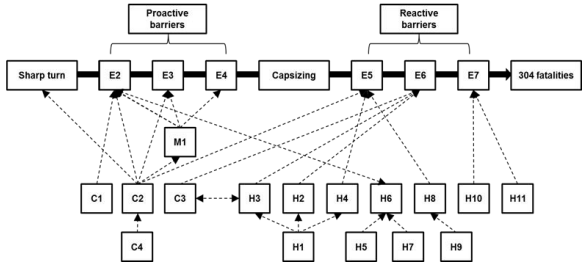


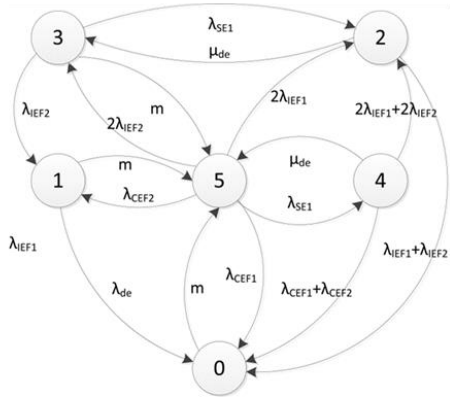
HEF
8.07 x 10^{-12} per ship year











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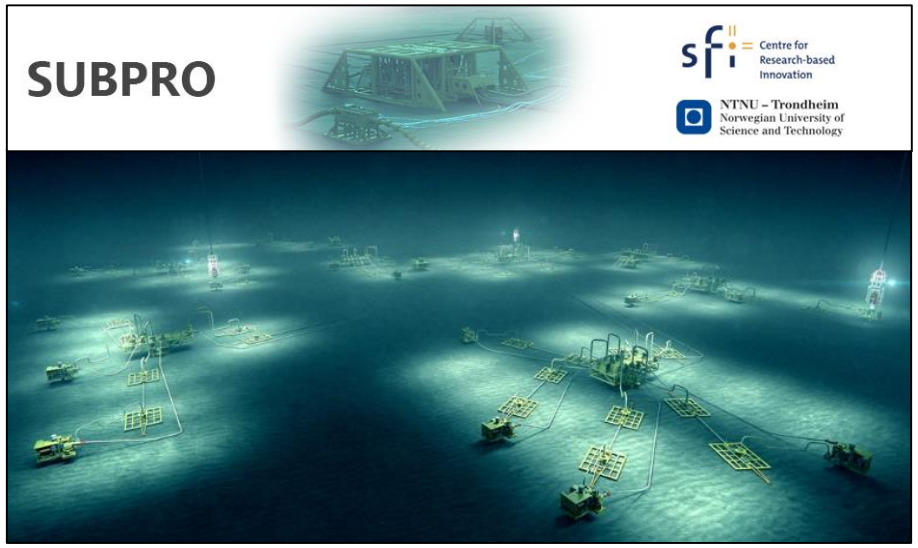
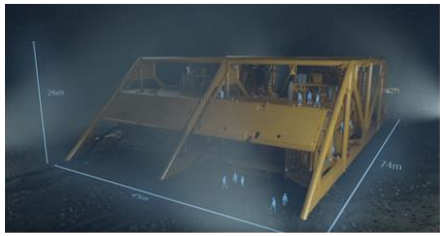
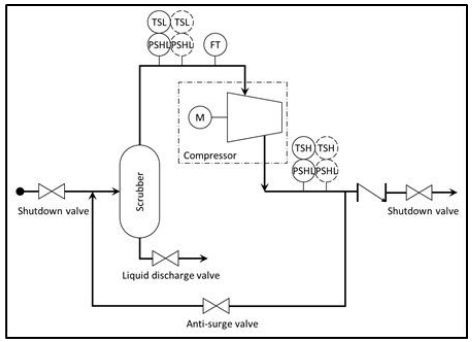
Postdoc

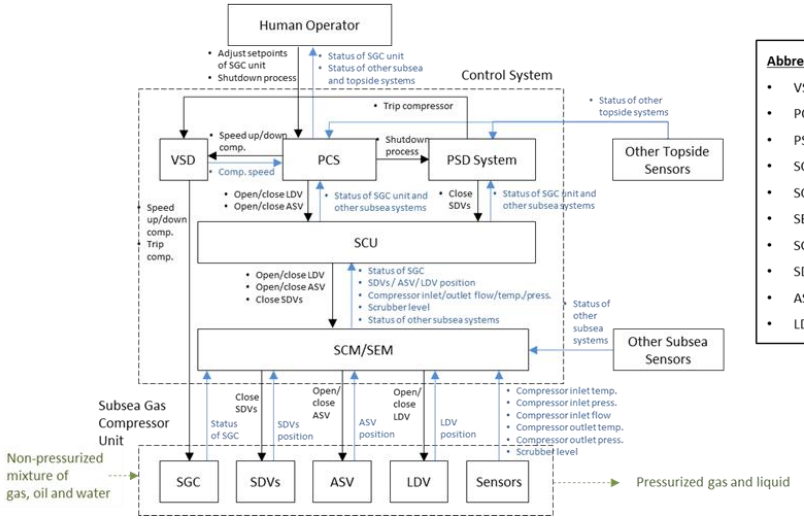
- SFI SUBPRO project

  - Hazard analysis for subsea systems









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Lectures

- HTOI (Human, Technology, Organization and Innovation) – PhD course
- Risk analysis for autonomous systems – master course
- Marine machinery and green ship technologies – master course
- Maintenance management and reliability engineering – bachelor course
- Master in Autonomy (new master program)

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Projects

A.WILHELMSEN FOUNDATION



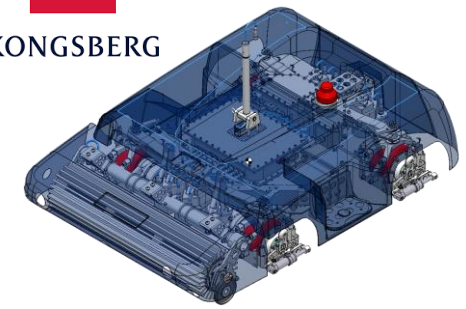
MARITIME ROBOTICS



AUTOSTRIF



KONGSBERG



SpillTech as
optimal solutions



KRISO
KOREA RESEARCH INSTITUTE OF SHIPS & OCEAN ENGINEERING



KR
KOREAN REGISTER



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2. Brief History
3. Major projects in Norway
4. Challenges
5. Summary

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Definition of Autonomous Ships

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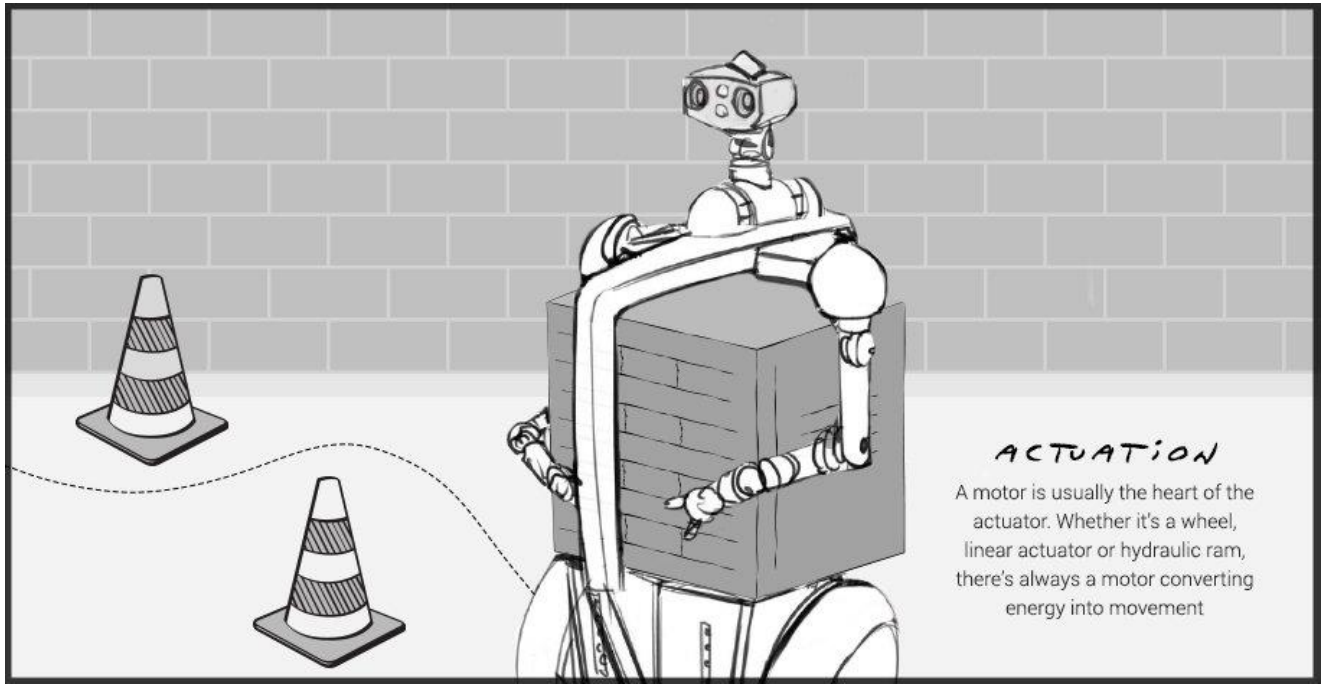
Definition of Autonomous

- Cambridge Dictionary

  - independent and having the power to make your own decisions

- Autonomous Robots



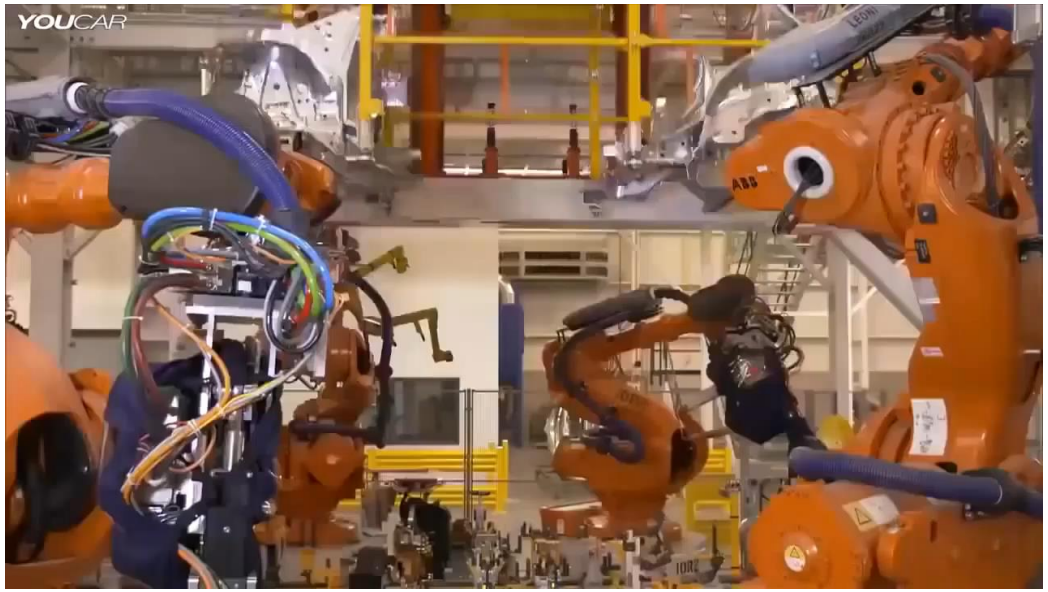
Source: Waypoint Robotics

Definition of Autonomous

- Automated vs. Autonomous

  - Automated: pre-programmed to perform a repetitive movement (CNC)

  - Autonomous: perception + decision + actuation





Definition of Autonomous Ships

- American Bureau of Shipping (ABS)

"A marine vessel with sensors, automated navigation, propulsion and auxiliary systems, with the decision logic to follow mission plans, sense the environment, adjust mission execution for the environment, and operate without human intervention"

Perception
Decision
Actuation
Perception
Decision
Actuation

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Definition of Autonomous Ships

- International Maritime Organization (IMO) – MSC 99/WP.9

"Maritime Autonomous Surface Ship (MASS) is defined as a ship which, to a varying degree, can operate independent of human interaction."

Degrees of autonomy

1. Ship with automated processes and decision support
2. Remotely controlled ship with seafarers on board
3. Remotely controlled ship without seafarers on board
4. Fully autonomous ship

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Norwegian Forum for Autonomous Ships



Table 1 – Ship autonomy types

	Manned bridge	Unmanned bridge - crew on board	Unmanned bridge - no crew on board
Decision support	Direct control No autonomy	Remote control	Remote control
Automatic	Automatic bridge	Automatic ship	Automatic ship
Constrained autonomous	-	Constrained autonomous	Constrained autonomous
Fully autonomous	-	-	Fully autonomous

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Direct Control

	Manned bridge	Unmanned bridge - crew on board	Unmanned bridge - no crew on board
Decision support	Direct control No autonomy	Remote control	Remote control
Automatic	Automatic bridge	Automatic ship	Automatic ship
Constrained autonomous	-	Constrained autonomous	Constrained autonomous
Fully autonomous	-	-	Fully autonomous

- On board crew is in control of the ship in all situation



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Remote Control

	Manned bridge	Unmanned bridge - crew on board	Unmanned bridge - no crew on board
Decision support	Direct control No autonomy	**Remote control**	**Remote control**
Automatic	Automatic bridge	Automatic ship	Automatic ship
Constrained autonomous	-	Constrained autonomous	Constrained autonomous
Fully autonomous	-	-	Fully autonomous

- No crew on board, no autonomy
- Direct control from shore control centre (SCC)



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Automatic Bridge

	Manned bridge	Unmanned bridge - crew on board	Unmanned bridge - no crew on board
Decision support	Direct control No autonomy	Remote control	Remote control
Automatic	**Automatic bridge**	Automatic ship	Automatic ship
Constrained autonomous	-	Constrained autonomous	Constrained autonomous
Fully autonomous	-	-	Fully autonomous

- On board crew monitors the control system
- Takes over control if necessary (decision by crew)



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Automatic Ship

	Manned bridge	Unmanned bridge - crew on board	Unmanned bridge - no crew on board
Decision support	Direct control No autonomy	Remote control	Remote control
Automatic	Automatic bridge	**Automatic ship**	**Automatic ship**
Constrained autonomous	-	Constrained autonomous	Constrained autonomous
Fully autonomous	-	-	Fully autonomous

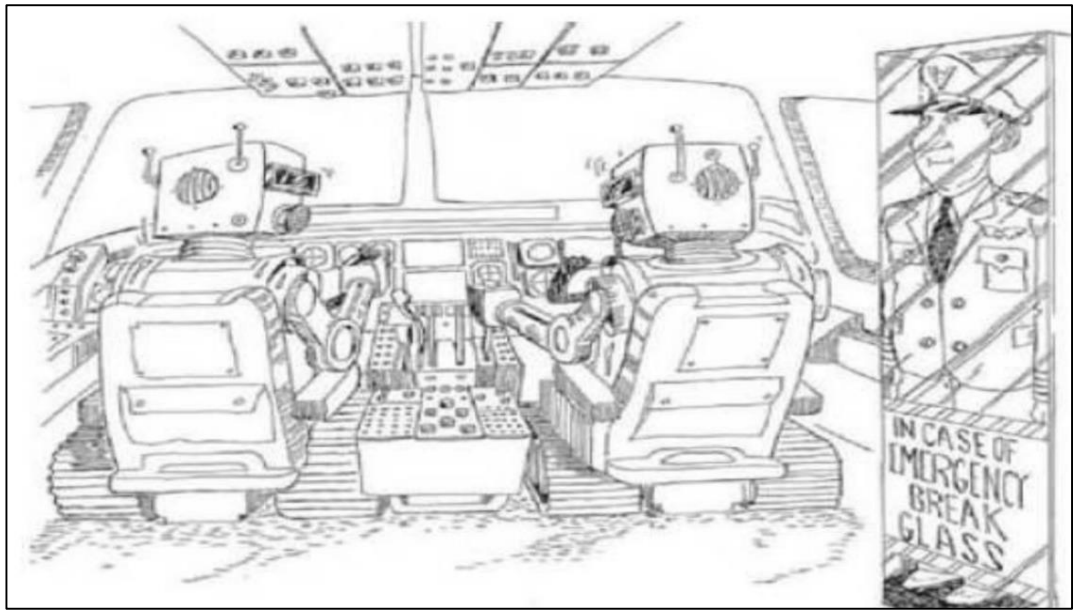
- No crew on board, low autonomy
- Monitored by SCC
- SCC takes over if necessary (decision by operator)



Constrained Autonomous

	Manned bridge	Unmanned bridge - crew on board	Unmanned bridge - no crew on board
Decision support	Direct control No autonomy	Remote control	Remote control
Automatic	Automatic bridge	Automatic ship	Automatic ship
Constrained autonomous	-	**Constrained autonomous**	**Constrained autonomous**
Fully autonomous	-	-	Fully autonomous

- Monitored by SCC, high autonomy
- SCC takes over if necessary (decision by autonomous system)



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Fully Autonomous

	Manned bridge	Unmanned bridge - crew on board	Unmanned bridge - no crew on board
Decision support	Direct control No autonomy	Remote control	Remote control
Automatic	Automatic bridge	Automatic ship	Automatic ship
Constrained autonomous	-	Constrained autonomous	Constrained autonomous
Fully autonomous	-	-	**Fully autonomous**

- Human completely out of the loop



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Level of Autonomy (MSC 100/5/6)

			No qualified operators on board but qualified operators available at a remote location	Qualified operators on board
Levels of autonomy	A0	**Manual** Manual operation and control of ship systems and functions, including basic individual system level automation for simple tasks and functions.		A0-B1
	A1	**Delegated** Permission is required for the execution of functions, decisions and actions; the operator can override the system at any stage.	A1-B0	A1-B1
	A2	**Supervised** The qualified operator is always informed of all decisions taken by the system. Permission of the qualified operator is not required for the ship system to execute functions, decisions and actions; the qualified operator can override the system at any stage.	A2-B0	A2-B1
	A3	**Autonomous** The qualified operator is informed by the system in case of emergency or when ship systems are outside of defined parameters. Permission of the qualified operator is not required for the ship system to execute functions, decisions and actions; the qualified operator can override the ship system when outside of defined parameters. Provided the boundaries of the ship system are not exceeded, "human control" becomes "human supervision".	A3-B0	A3-B1

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Brief History

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Number of crew aboard

- **Ocean Going Vessels**
  - 1860: 250 persons
  - 1880: 140 persons
  - 1900: 100 persons
  - 1950: 40 persons (diesel engine)
  - 2000: 16 persons
  - 20??: 0 person (autonomous unmanned ship)



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1970s

- Ships and Shipping of tomorrow

"In this age of … automation, it would not be difficult to imagine a ship without a crew"

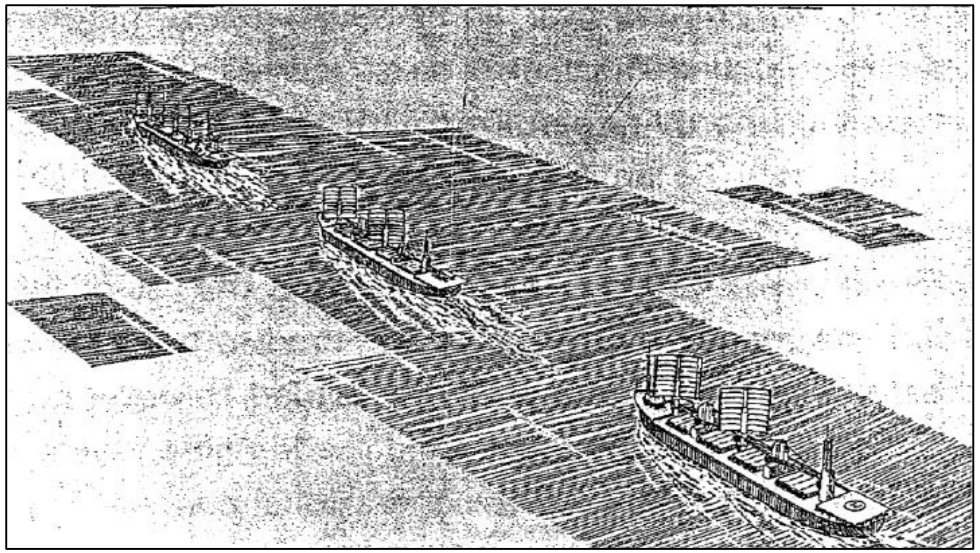


Source: DNV-GL

1980s

- Japanese Intelligent Ship Project

  aimed at
  “bring about ‘intelligent ships’ that can function without help from the crew”



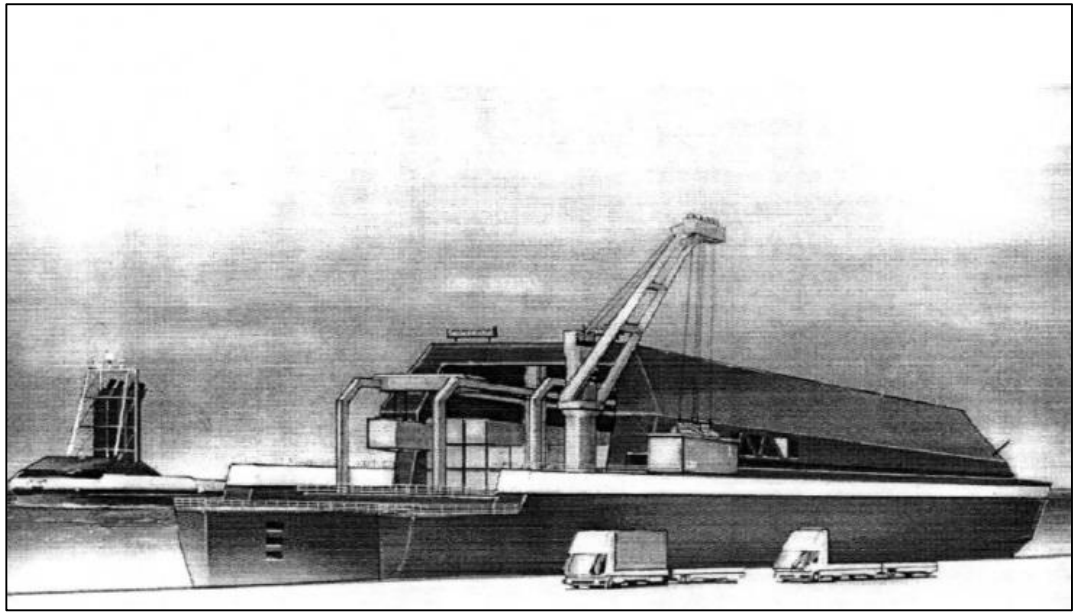
Source: DNV-GL

1994

- Kai Levander

Ship without crew for short-sea shipping

“ A ship with no crew onboard could travel aided by the GPS chain and guided from the traffic stations”



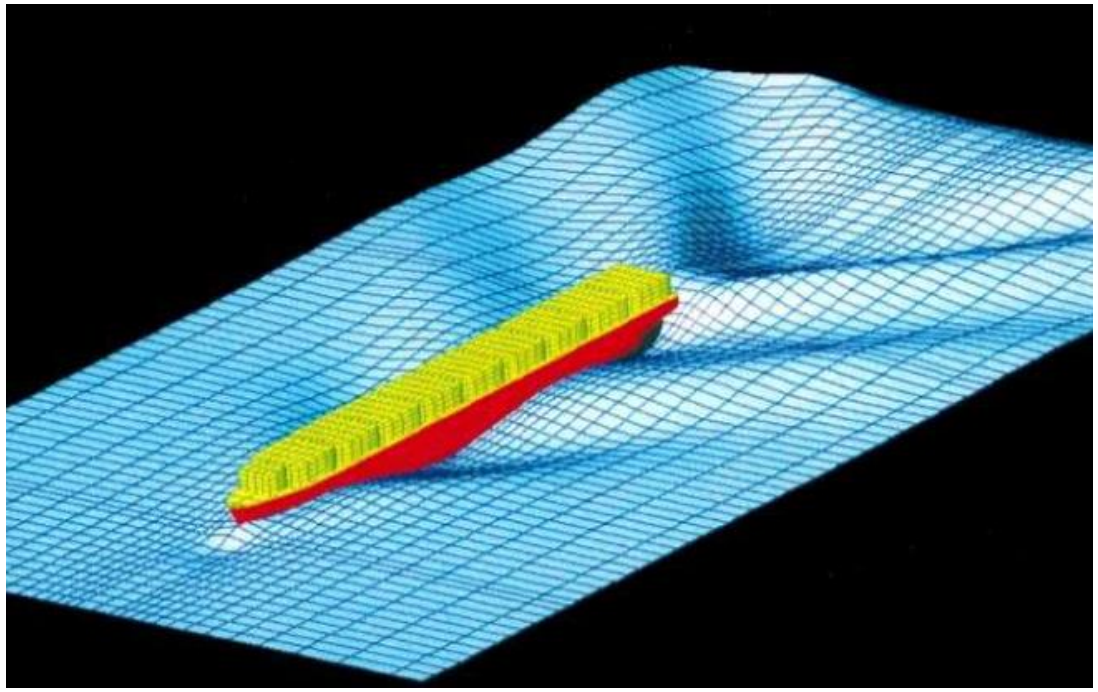
Source: DNV-GL

1996

- Bertram & Kaeding

Combination of AI and tele-operation

Feasible but not economically attractive (due to maintenance)



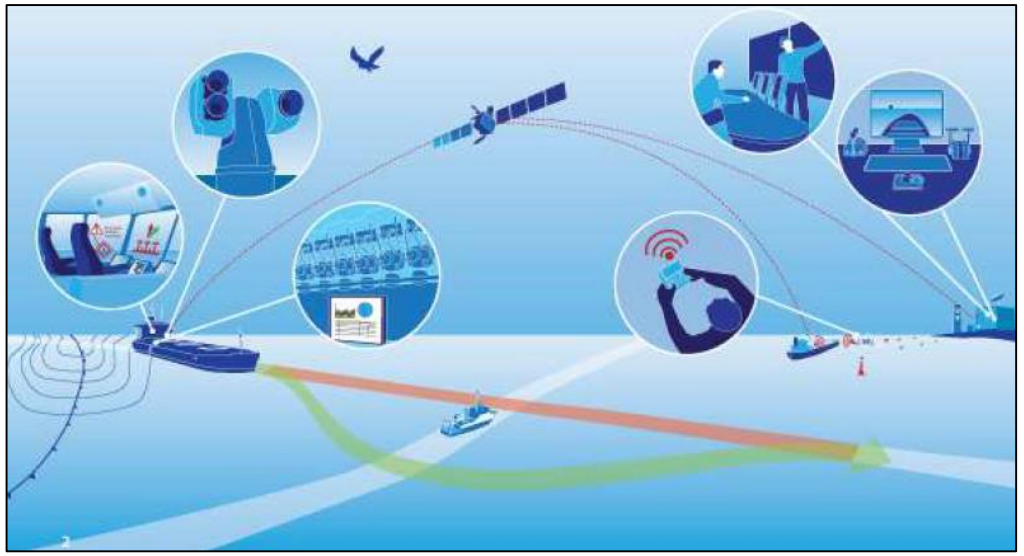
Source: DNV-GL

2012

- MUNIN (EU Project)

  Unmanned bulk carrier simulation – combination of AI and tele-operation

  "Even if it is doubtful whether the unmanned merchant ships will be a reality in the short term, the concept of an autonomous ship provides an important pathway for a sustainable development of maritime transport"



Source: DNV-GL

2013

- Oskar Levander (Rolls-Royce)

  Unmanned containerships – combination of AI and tele-operation

  “The idea … is not new, … the difference is that the technology now exists”



Source: DNV-GL

2014

- Revolt Project (DNV-GL)

  Unmanned container feeder vessel – battery powered

  “Building and operating this vessel would be possible with today’s technology”



Source: DNV-GL

2017

- YARA Birkeland

Fully autonomous operation by 2022

"The vessel YARA Birkeland will be the world's first fully electric and autonomous container ship, with zero emissions"



Source: Kongsberg

2018

- SVAN (Safer Vessel with Autonomous Navigation)

  Rolls-Royce and Finferries

  Fully autonomous ferry operation successfully demonstrated in 2018

  (Falco was originally built in 1993)







2020

- ASKO Barge



ASKO with Kongsberg and Massterly

Two autonomous barge (LOA 67m, battery propulsion, 16 trailers)

Can reduce 2 million km truck operation per year (approx. 5 000 tons CO2)





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Major Autonomous Ship Projects in Norway

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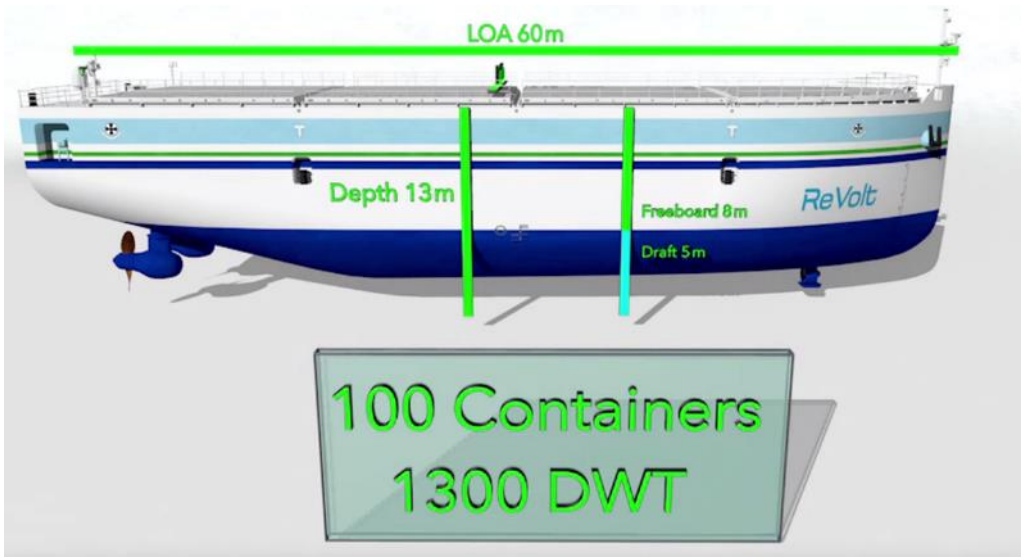
Revolt Project (2014)



Revolt Project (2014)



Main particulars	
LOA	60.23 m
LPP	57.23 m
Beam	14.5 m
Depth	13.18 m
[illegible]	[illegible]
Average service speed in NEZ is 8.7 knots	
Service speed	6 kn
Capacity	
Cargo capacity	100 TEU
Deadweight	1,250 mt
Cruising range	100 nm
Machinery	
Battery	3,000 kWh
Propulsion	
Azimuth pods with 2 blades (3 m diameter)	2
Retractable bow thruster	1

Source: DNV-GL

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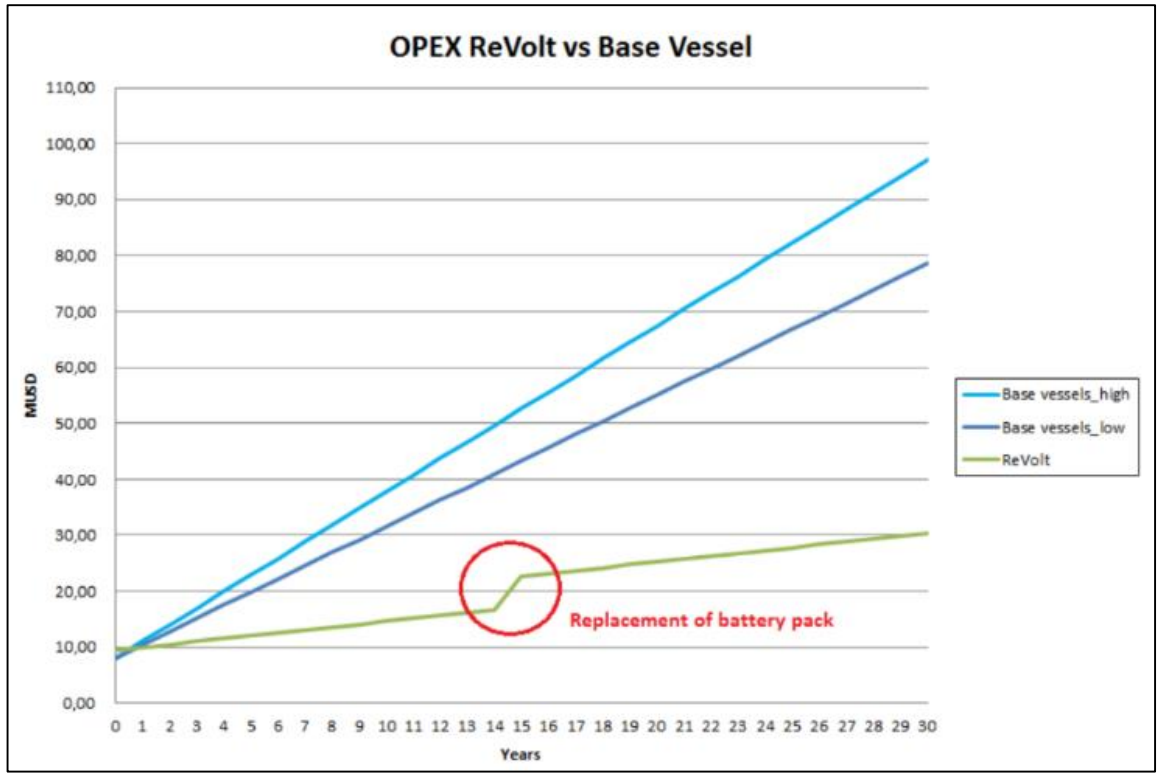
Revolt Project (2014)







Source: DNV-GL

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YARA Birkeland (2017)

Knowledge grows



Key facts

- Established as Norsk Hydro in 1905
- Demerged as Yara International ASA in 2004
- President and CEO, Svein Tore Holsether, since Sept. 2015
- Headquartered in Oslo, Norway
- Listed on the Oslo Stock Exchange
- Around 16,000 employees
- Operations in over 60 countries

Key figures: 2019

- Revenues: USD 12.9 billion
- EBITDA: USD 2.1 billion
- Total Deliveries: 38 million tonnes
- Sales & Marketing deliveries: 30.5 million tonnes
- New Business deliveries: 4.1 million tonnes
- Ammonia trade: 2.5 million tonnes

YARA Birkeland (2017)



More than 100 travels per day
Approx. 40,000 travels per year



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YARA Birkeland (2017)





Launched in February 2020 (Romania)

Main particulars

- **Length o.a.**: 79,5 m
- **Length p.p.**: 72,4 m
- **Width mld.**: 14,8 m
- **Depth shelter deck**: 10,8 m
- **Draught (full)**: 6 m
- **Draught (ballast)**: 3 m
- **Service speed**: 6 knots
- **Max speed**: 13 knots

Capacity

- **Cargo capacity**: 120 TEU
- **Deadweight**: 3 200 mt

Propulsion

- **Propulsion system**: Electric
- **Propellers**: 2 Azimuth pods
- **Thrusters**: 2 Tunnel thruster
- **Battery pack**: 7 – 9 MWh

KONGSBERG

massterly
a Kongsberg Wilhelmsen joint venture

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ASKO (2020)





Norway's largest grocery wholesaler

21 warehouses with 800 trucks on the roads everyday

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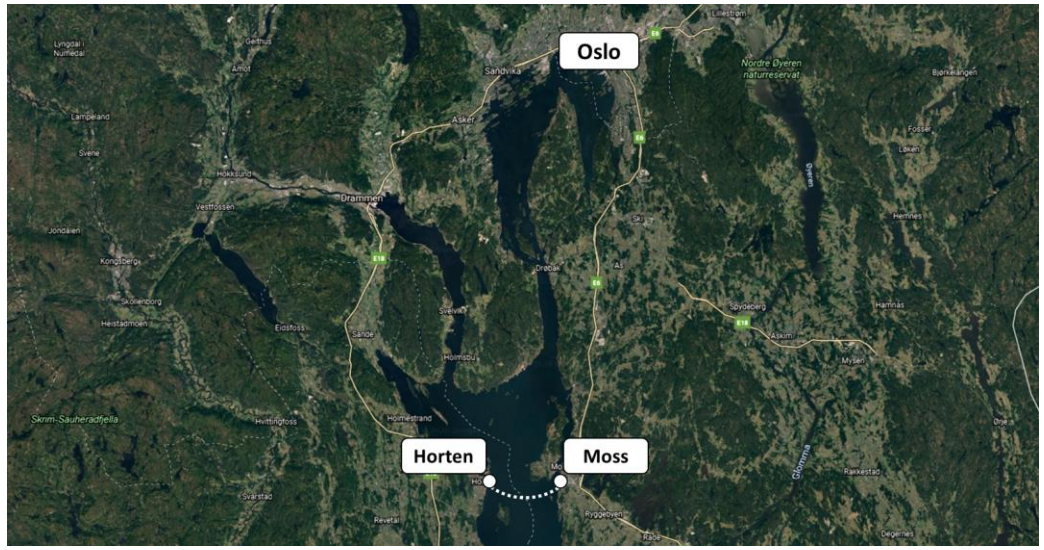
ASKO (2020)





Replace 2 million kilometres of truck transport every year (5,000 tonnes of CO2)

Cochin Shipyard in India (to be delivered early 2022)

LOA 67m, Battery propulsion (1,846 kWh), 16 trailers

119 MNOK by Norwegian government body ENOVA (약 150억원)

KONGSBERG

massterly
a Kongsberg Wilhelmsen joint venture

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AUTOSHIP (2020)

AUTOSHIP
Autonomous Shipping Initiative for European Waters

Funded by Horizon 2020 - 200 MNOK (약 260억원)

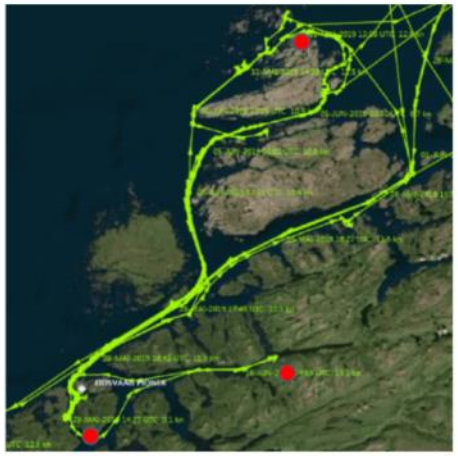
Kongsberg, SINTEF, University of Strathclyde, etc.





Operational focus	Transit, docking & undocking, lock navigation, continuous operation	Transit, docking & undocking, cargo operation, fish farm interaction, weather window
Autonomy level	4. Constrianed Autonomous & Continously Unmanned	3. Constrained autonomous & Periodically unmanned bridge - high degree of automatic operations
Area of operation	Inland Waterways	Open Sea
Rules & regulations	National Authorities and local governing bodies	Flag state, Classification Societies, IMO
Shore operation	Logistical and transport planning, monitoring, exception handling	Route planning, monitoring, remote controlled operations, exception handling, decision support
Infrastructure	RIS (River Information System), VTS, Lock interaction	Local / Coastal VTS
Connectivity	Near land possible use of mobile networks and shorter range communication	Shorter range communication where available, otherwise satellite communications





S01 Building and Operating Autonomous Ship at TRL 7

S02 Demonstrating Key Enabling Technologies

S03 Develop Standard, tools and methods

S04 Digital Upgrade

S05 Skilled and Updated Operators

S06 Regulatory and socio-economic Framework

S07 Business case and models

S08 Roadmap to intercontinental R&A navigation

S09 Communication acceptance and dissemination

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Autonomous Ship Projects in Norway

- Projects by Private Companies (User Driven)

- Entire Autonomous Logistics





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COVID-19



MARINELINK

Shipbuilding Offshore Coastal/Inland Government Equipment Training Law & Regulations

Yara Birkeland Project Paused Due to COVID-19

Eric Haun, Editor
Eric Haun is editor of Marine News. He has covered the commercial maritime and...

May 11, 2020



Yara Birkeland was launched in Romania in February 2020 (Photo; Yara International ASA)

Plans to launch the world's first all-electric autonomous container vessel Yara Birkeland have been shelved due to the coronavirus pandemic and uncertain market conditions, said Yara International, the Norwegian company behind the project.

"Due to the COVID-19 pandemic and the changed global outlook, Yara has decided to pause further development of the vessel and will assess next steps together with its partners," the company said.

In 2017, Yara partnered with technology company Kongsberg to build the fully battery-powered container vessel, designed by Marin Teknikk to transport chemicals and fertilizer autonomously and without emissions along the coast of Norway.

The 120 TEU open hatch container feeder was initially due to enter service as a manned vessel in 2018 before being converted for autonomous operations by 2020. Before the project was shelved, those dates had shifted to 2020 delivery and fully autonomous operations by 2022, according to Kongsberg's website.

The hull of the 80-meter Yara Birkeland was launched at Vard Braila in Romania in February 2020 and arrived Sunday at Norway's Vard Brevik shipyard where the vessel was slated to be fitted with control and navigation systems and undergo testing before autumn delivery, Kristin Nordal, Yara International's Vice President Corporate Communications, told *MarineLink*.



KONGSBERG MARITIME AND MASSTERLY TO EQUIP AND OPERATE TWO ZERO-EMISSION AUTONOMOUS VESSELS FOR ASKO

01 Sep 2020



The new vessels will replace 2 million kilometres of truck transport, saving 5,000 tonnes of CO2 annually

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Challenges of Autonomous Ships

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Forecasting Artificial Intelligence in the Future

- *"there are now in the world machines that think, that learn, and that create. Moreover, their ability to do these things is going to increase rapidly until in a visible future the range of problems they can handle will be coextensive with the range to which the human mind has been applied.."*

  - AI pioneer, Herbert Simon

- *"with the then-plausible goal of building a fully intelligent machine in a decade."*

  - Founder of Stanford AI project, John McCarthy

- *"In from three to eight years we will have a machine with the general intelligence of an average human being"*

  - AI pioneer, Marvin Minsky

Source: https://www.openphilanthropy.org/

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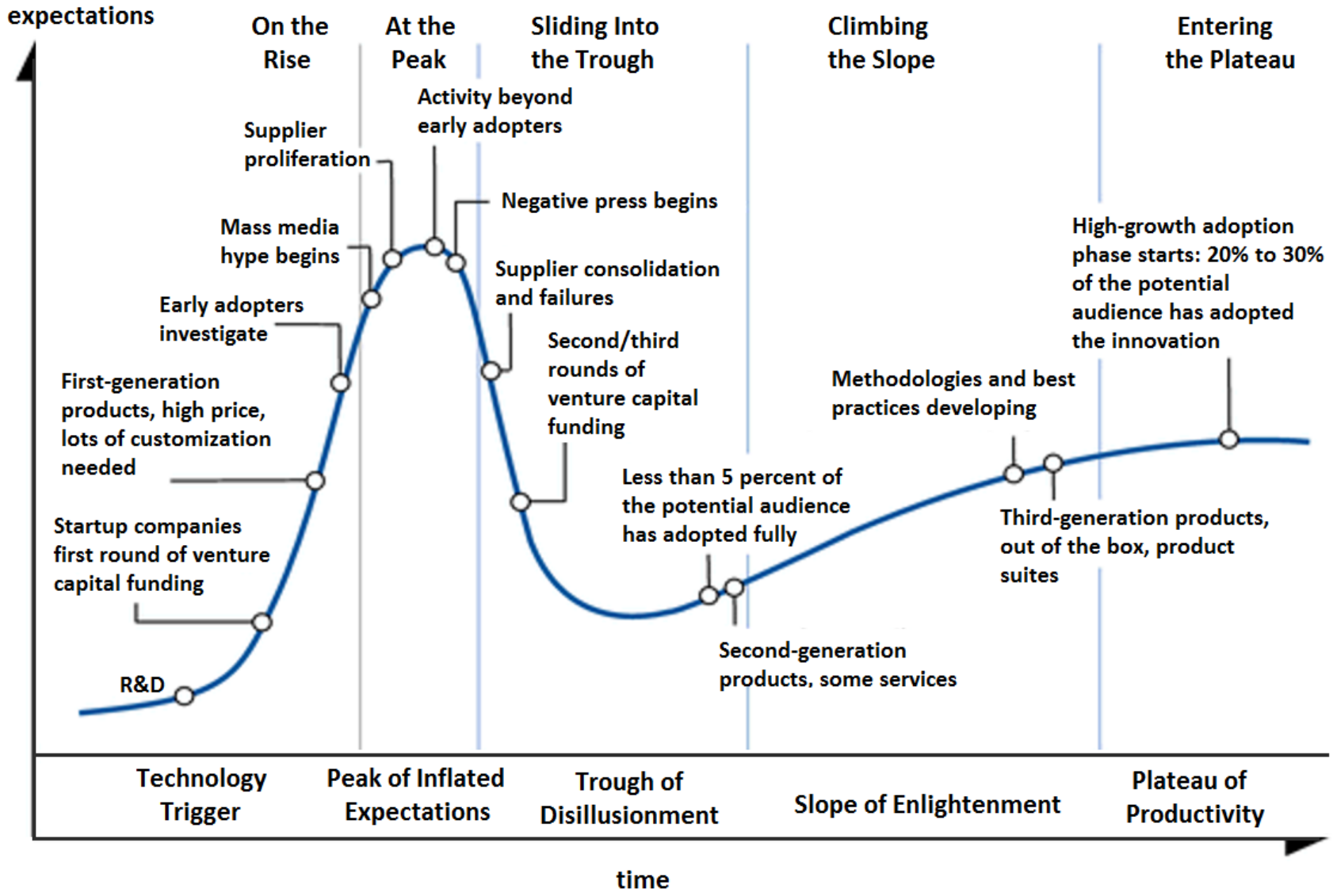
Hype Cycle



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Hype Cycle

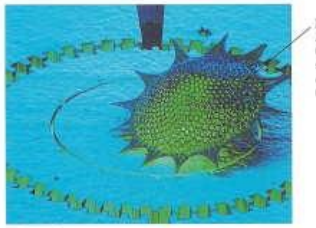
Nanorobots

Technology is shrinking fast. Computing technology that would have filled a warehouse 30 years ago can now be squeezed onto a chip a fraction of the size of your thumbnail. The very smallest scale of engineering is called nanotechnology. A nanometer is a billionth of a meter, about the width of ten atoms. Nanotechnology may, one day, be capable of producing fully working robots to that scale, called nanorobots or nanobots. Working at an almost atomic level, nanobots could build complex items cheaply and repair clothes, equipment, and even people without being noticed. They could also be used to rid the atmosphere of pollution and to repair holes in the ozone layer.



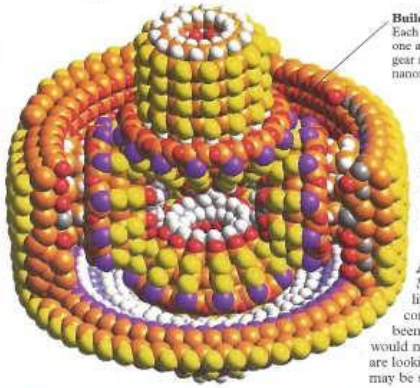
Bottom up
Researchers are looking at different ways to construct nanobots. The "bottom up" approach uses individual atoms and molecules as building blocks. This stick figure was created from just 28 carbon monoxide molecules.

A mere wisp
A row of 20,000 of these stick figures is more narrow than a human hair.



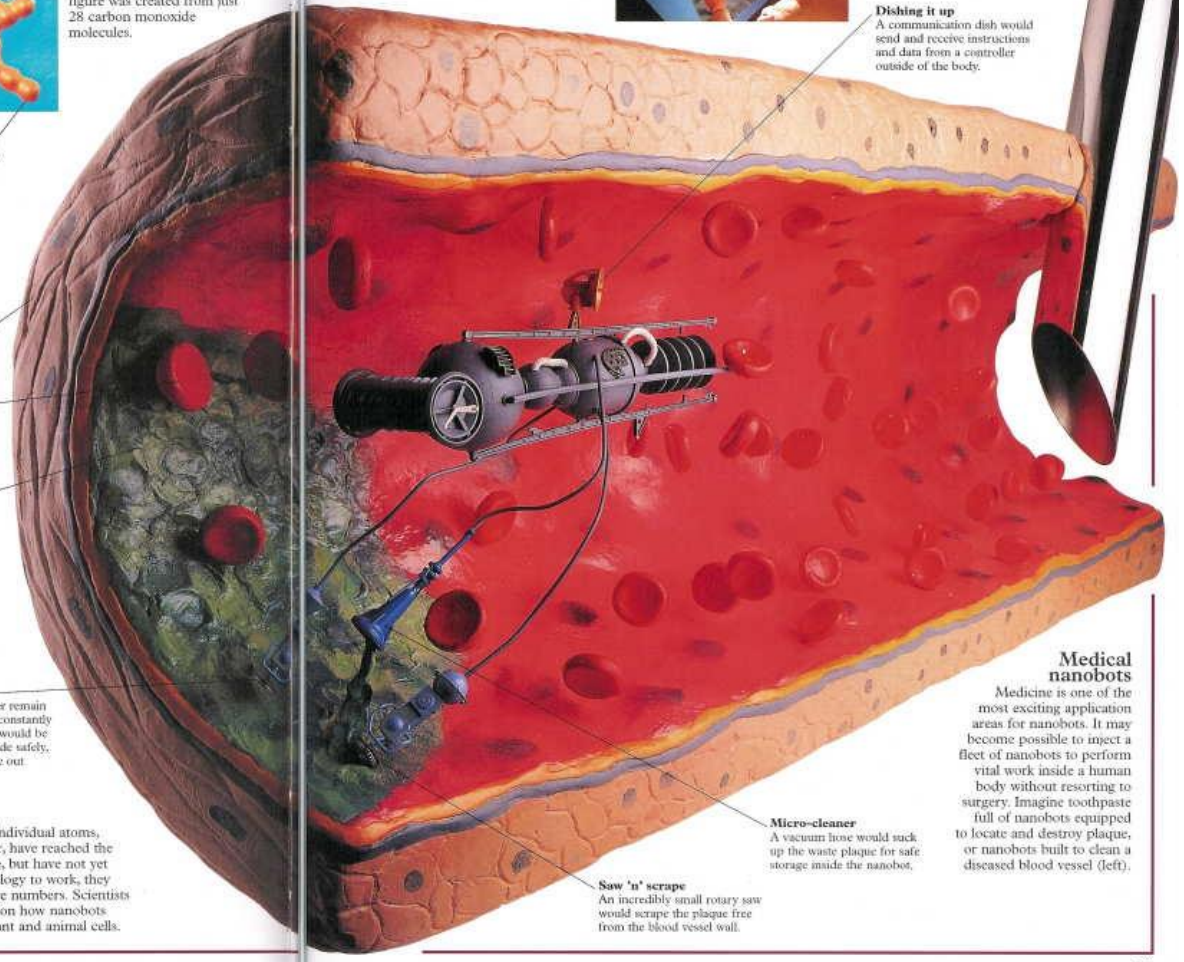
Putting it in context
A plankton skeleton, just 0.008 in (0.2 mm) across, sits on one of the engine's cogs, measuring 0.02 in (0.5 mm).

Top down
Known as "top down," one potential way of building nanomachines is to miniaturize existing machines. There have been some incredible feats, including this fully working electric motor, just 0.07 in (1.8 mm) in size.



Building atoms
Each ball represents one atom. The whole gear measures just a few nanometers in diameter.

A nanogear
Machines made from individual atoms, like this differential gear, have reached the computer modeling stage, but have not yet been built. For nanotechnology to work, they would need to be made in huge numbers. Scientists are looking to nature for ideas on how nanobots may be self-replicating, like plant and animal cells.



38

39

Source: BioTech177 (2009)

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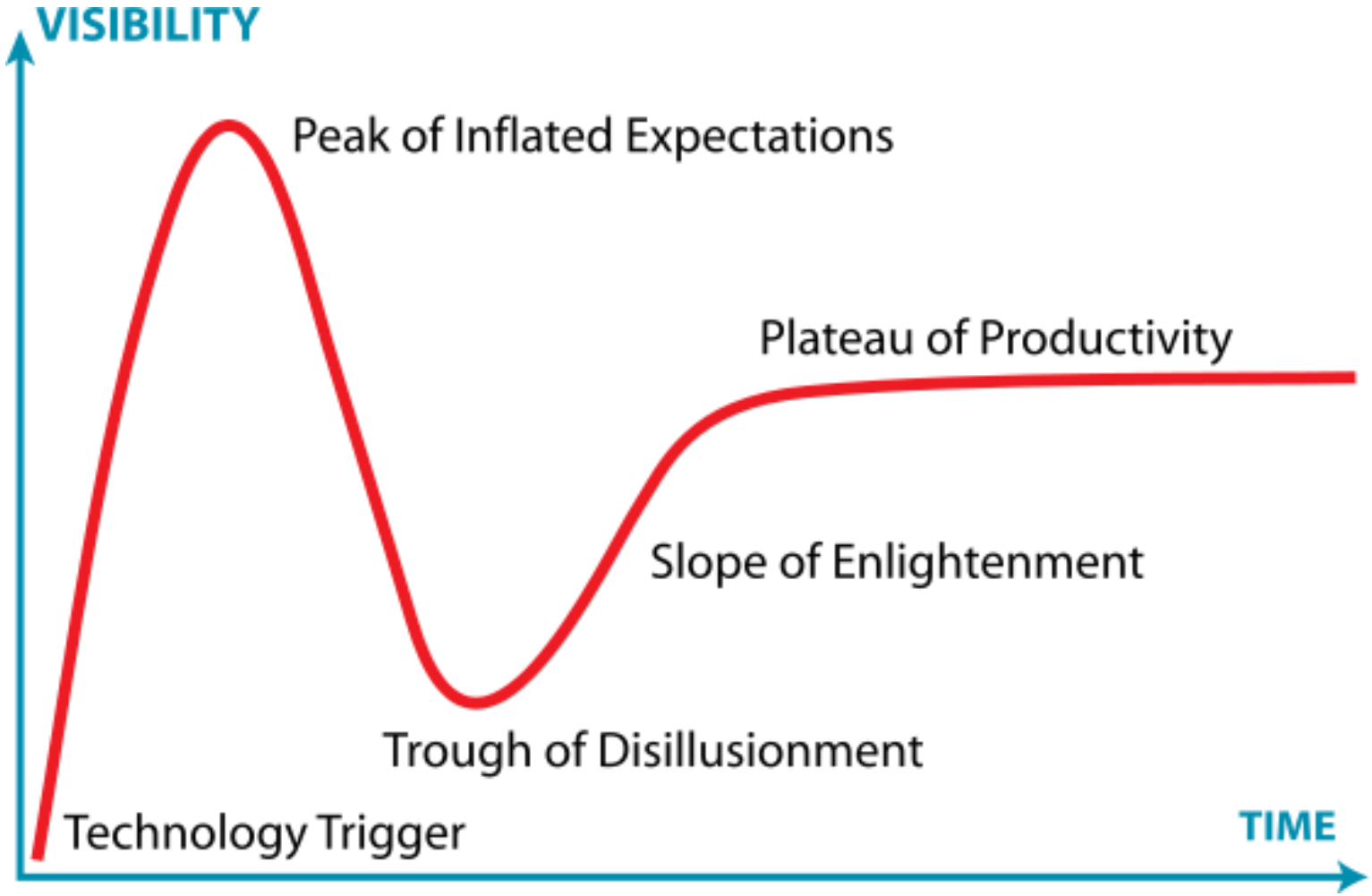
Hype Cycle



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European Commission

THE INTERNATIONAL
SHIP AUTONOMY AND
SUSTAINABILITY SUMMIT
EU 2020

NFAS

What is the *real* future of autonomous ships?

Virtual event - 30 November 2020

Live poll

120

Q1: By when do you expect first fully autonomous ships in global/intercontinental trade?

2025-2029

38%

2030-2034

31%

2035-2040

12%

after 2040

10%

before 2025

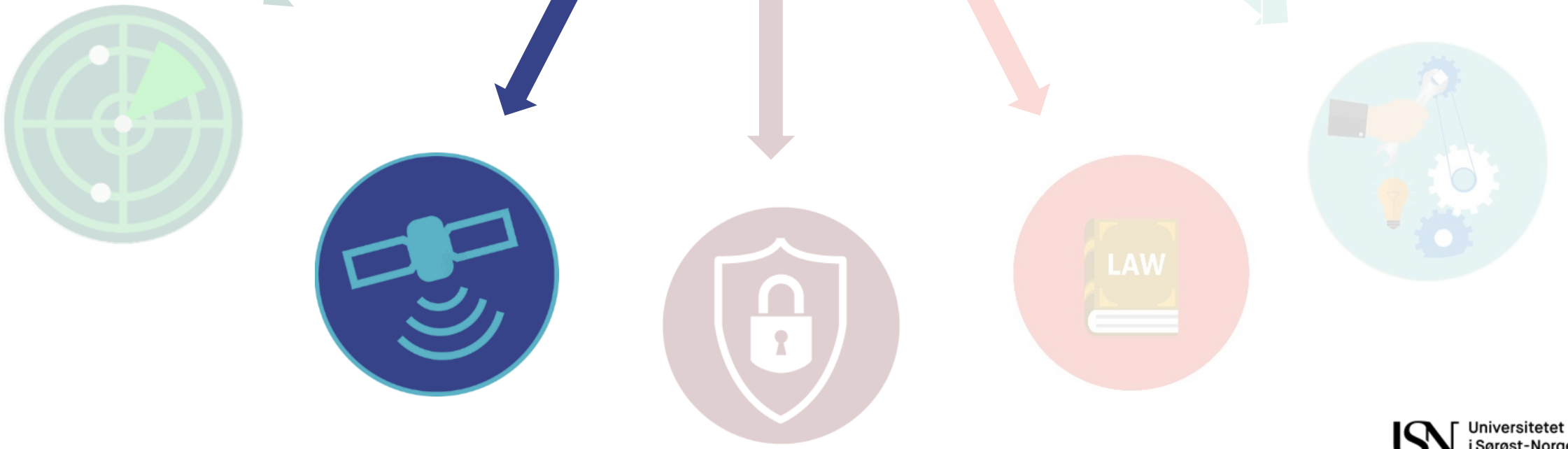
9%

EDIT RESPONSE



Main Challenges





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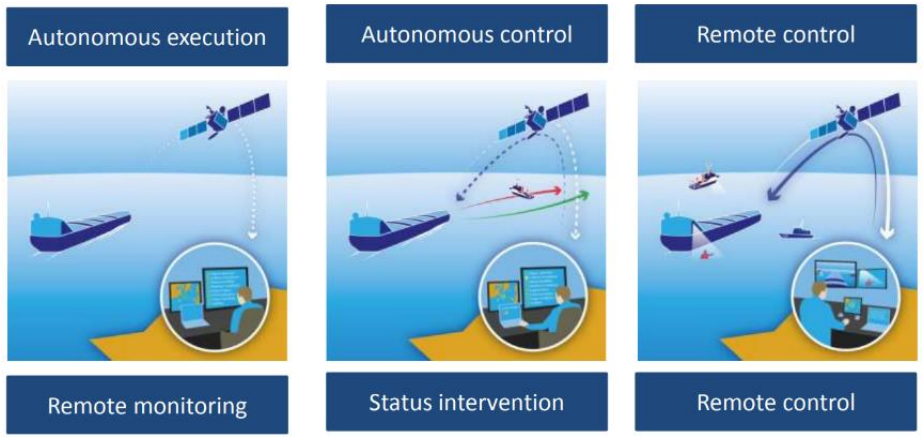
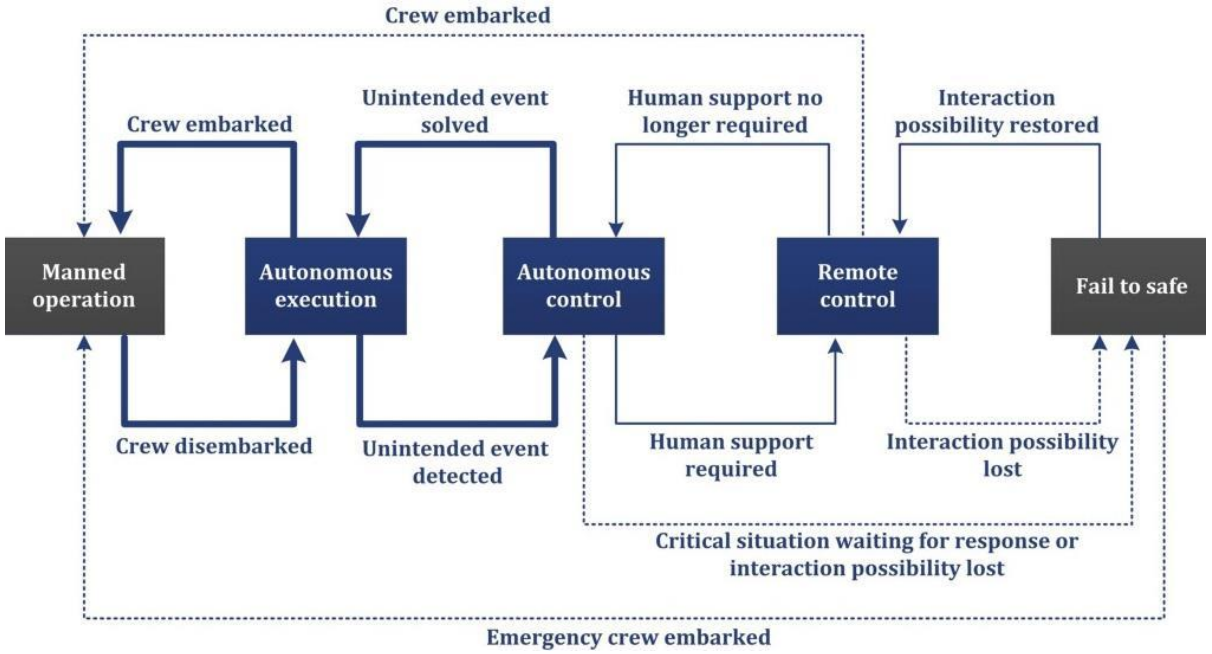
Communication







Source: MUNIN Project

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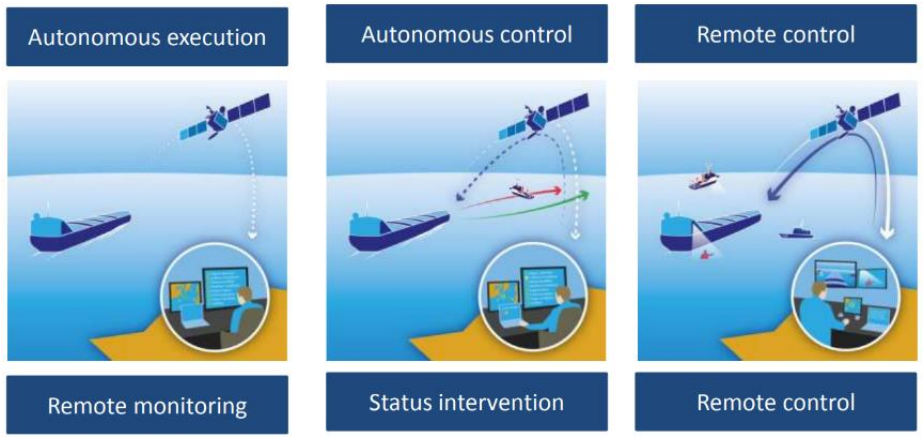
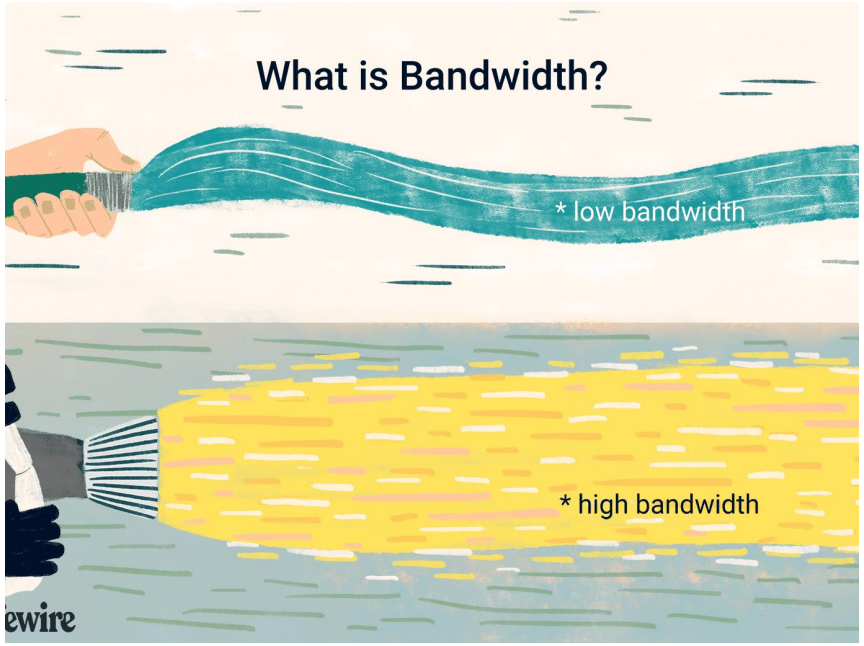
Communication



Remote control in Emergency





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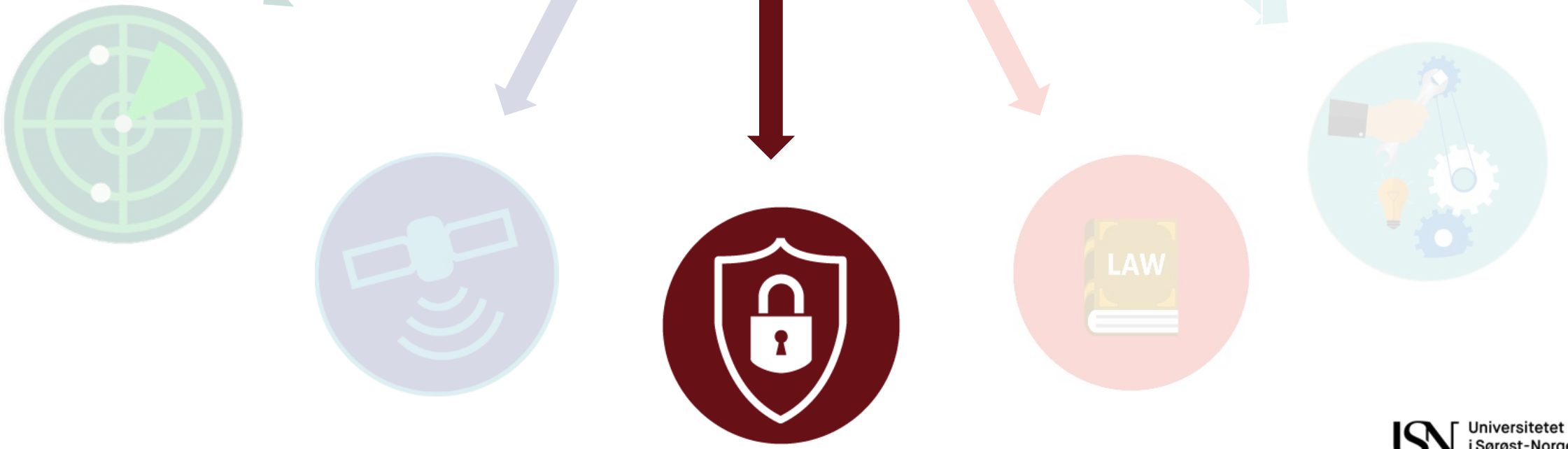
Main Challenges





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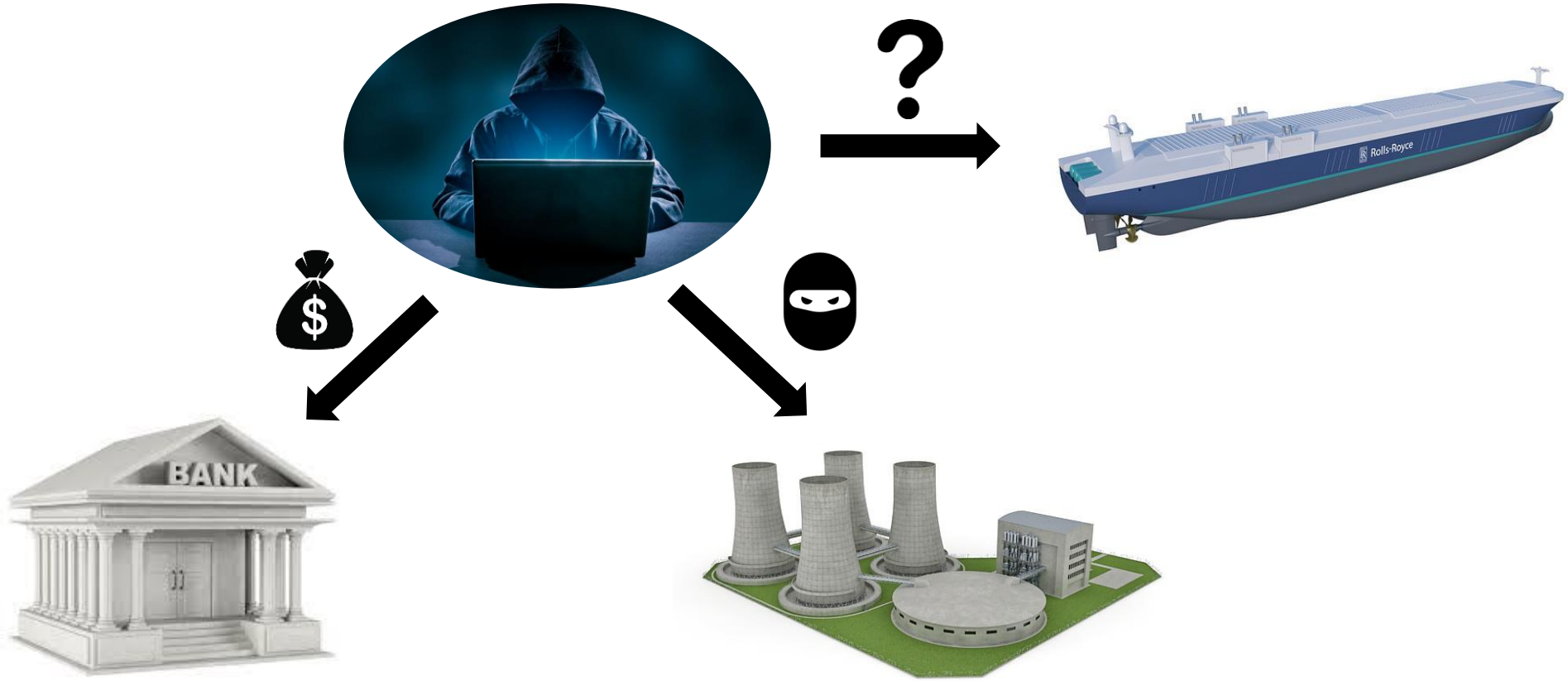
Cyber Security

MUNIN

"… it is unclear whether unmanned and autonomous ships are attractive to such attacks at all."



Cyber Security

- Floating bridge to cross Sognefjord
  - Resistance: 1 563 MJ
  - Corresponds to 31 500 DWT, travelling at 17.7 knots
  - Significant number of cargo ships in Norwegian coast are larger



Source: Vinnem et al. (2018), Risk from cyberattacks on autonomous ships

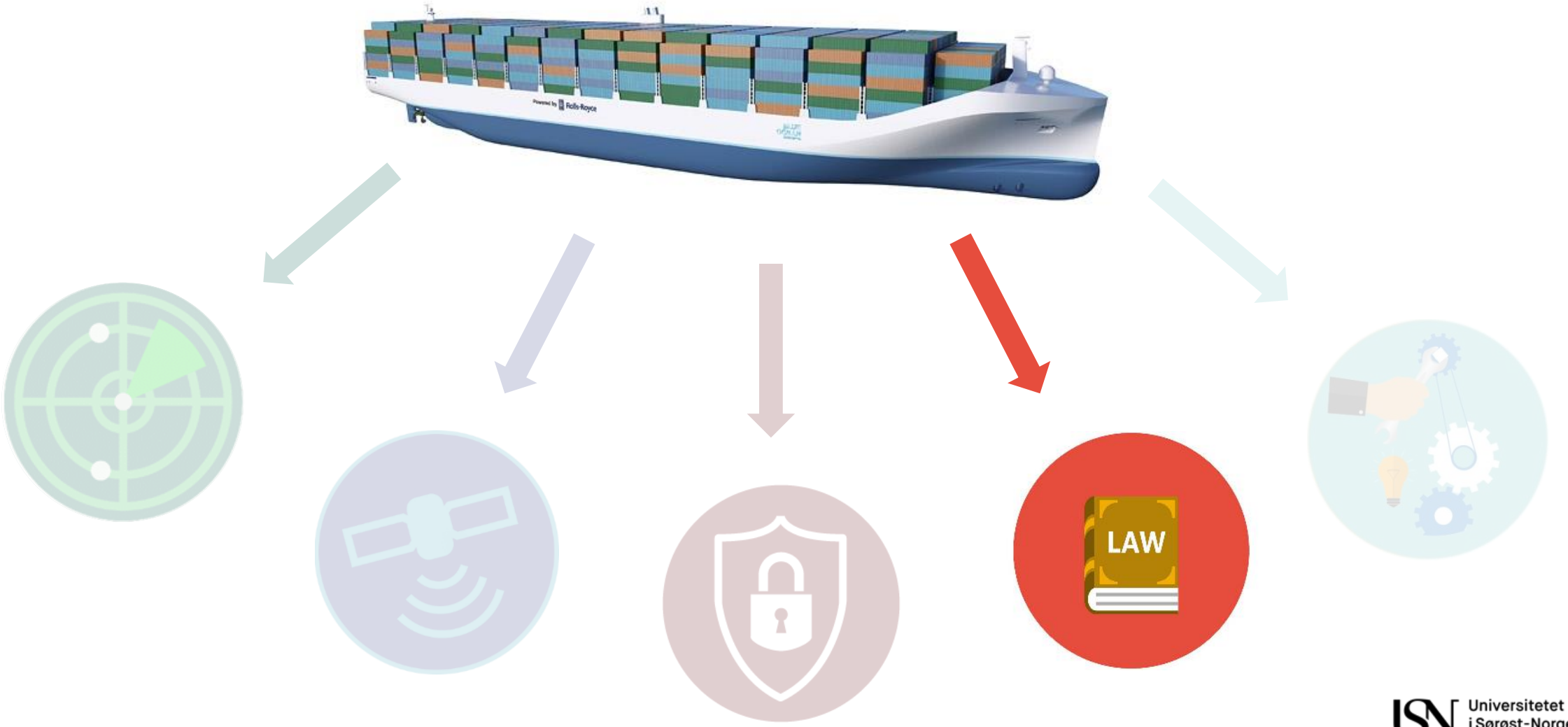
Cyber Security

- Offshore installations
  - Resistance: 14 MJ traditionally for all structures
  - Largest concrete installations = approx. 200 MJ
  - Corresponds to 5 000 DWT, travelling at 12 knots



Source: Vinnem et al. (2018), Risk from cyberattacks on autonomous ships

Main Challenges



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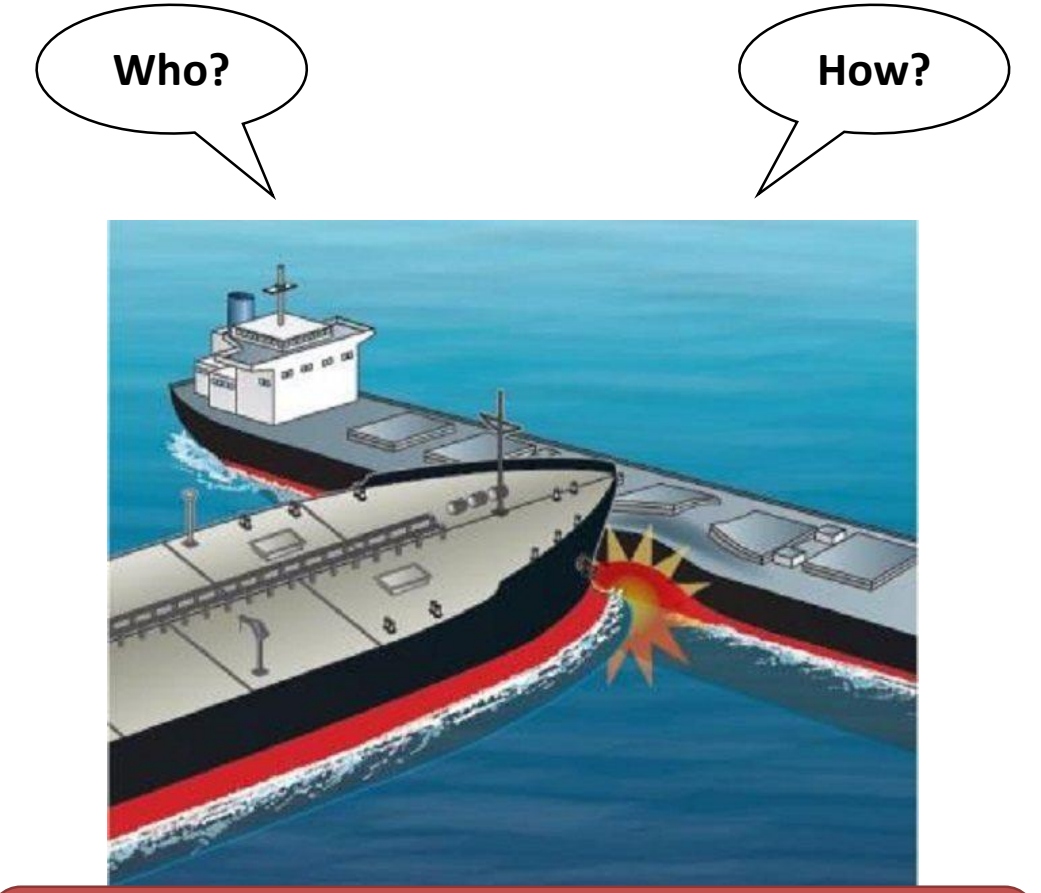
Rule and Regulation



As safe as manned ships?

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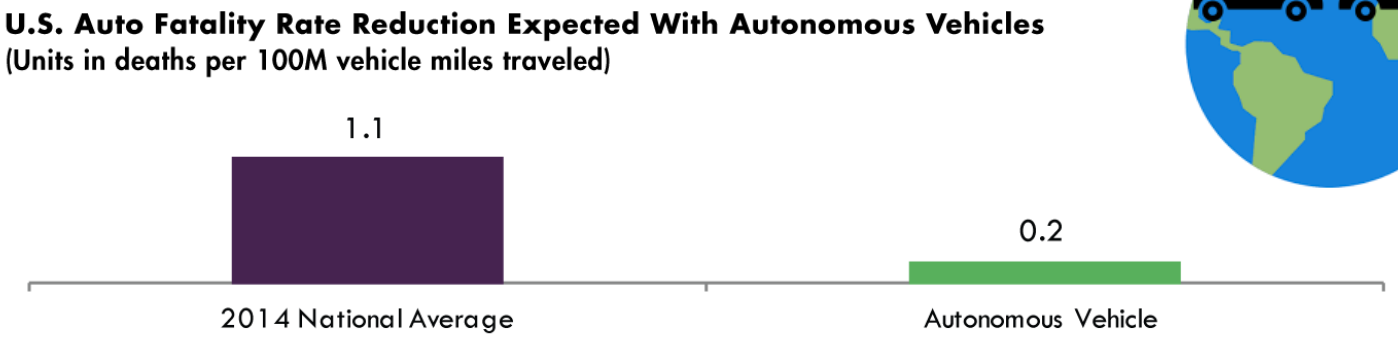
Rule and Regulation

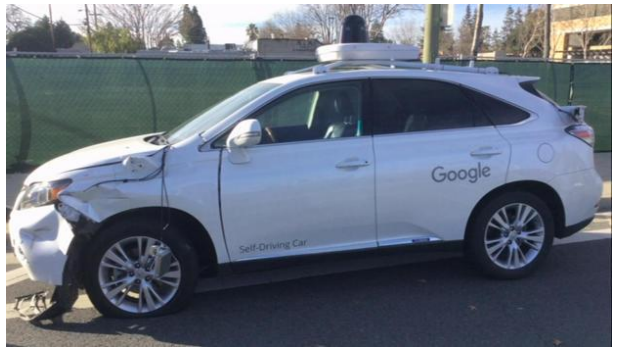
1.25 million (WHO)





Source: ARK Investment Management LLC





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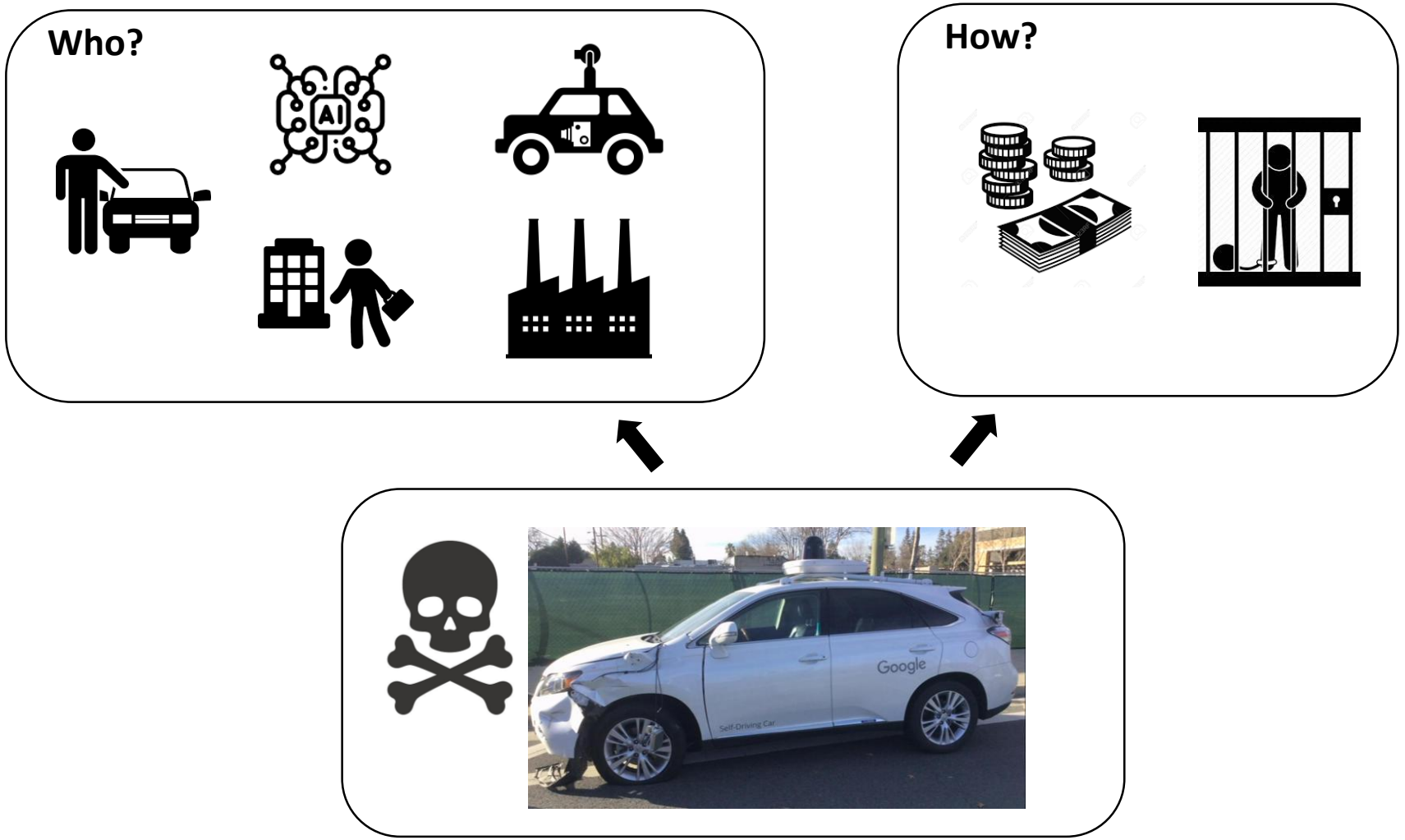
Rule and Regulation



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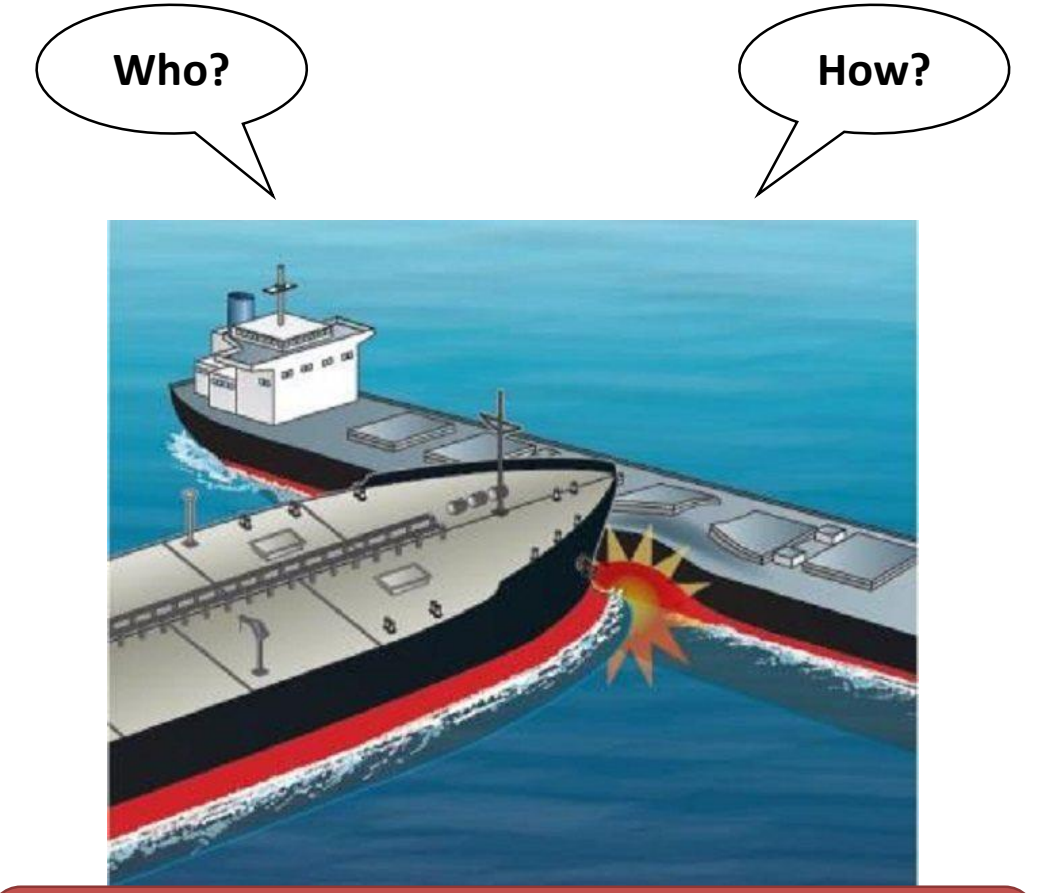

As safe as manned ships?

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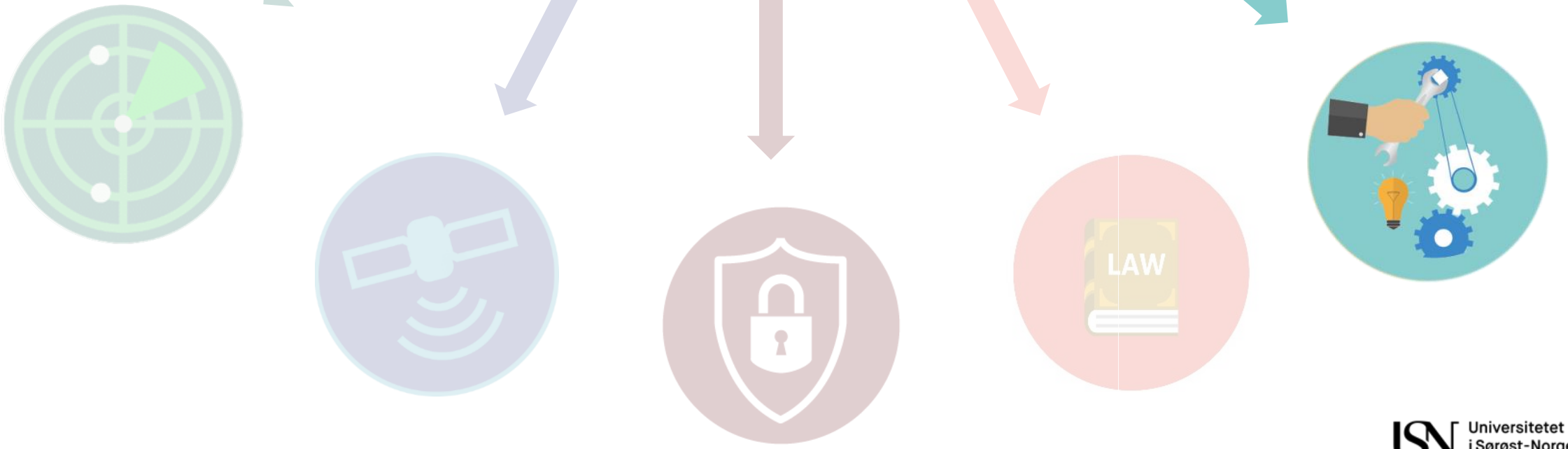
Main Challenges





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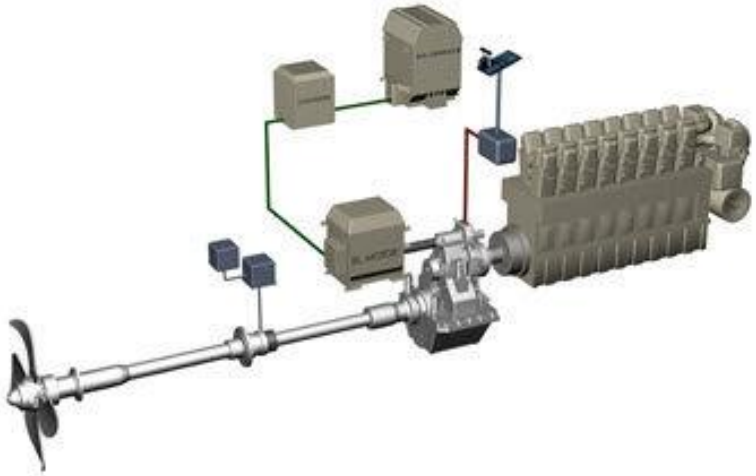
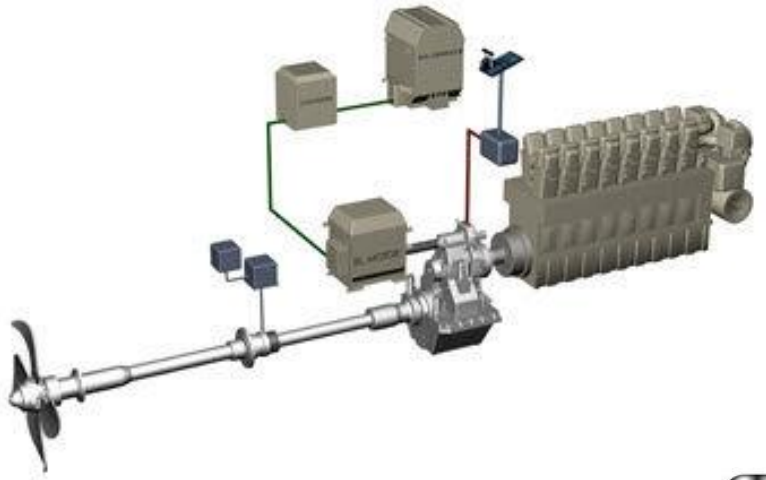
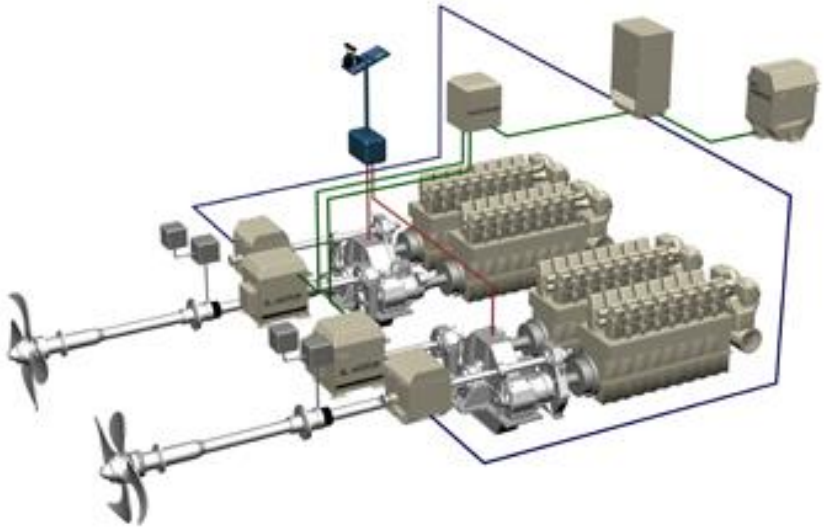
Repair and Maintenance





Repair and Maintenance









Repair and Maintenance



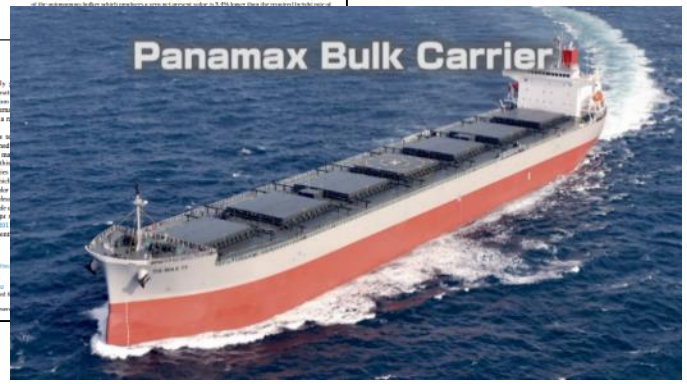


Repair and Maintenance


Research in Transportation Business & Management

Analyzing the economic benefit of unmanned autonomous ships: An exploratory cost-comparison between an autonomous and a conventional bulk carrier

Lutz Kretschmann, Hans-Christoph Burmeister, Carlos Jahn



Ship particulars of the reference panamax bulker.
Source: authors.

Ship particular	Value
Length over all	230 m
Breadth	32 m
Design draught	14,5 m
Service speed	15,5 kn
Displacement	90,600 t
Main engine	10,230 kW



Operating costs	Voyage costs	Capital costs
Crew wages (−) Crew related costs (−) Shore control center (+) Maintenance crews (+)	Air resistance (−) Light ship weight (−) Hotel system (−) Boarding crew for port calls (+)	Deckhouse (−) Hotel system (−) Redundant technical systems (+) Autonomous ship technology (+)

Source: Kretschmann et al. (2017), Analysing the economic benefit of unmanned autonomous ships

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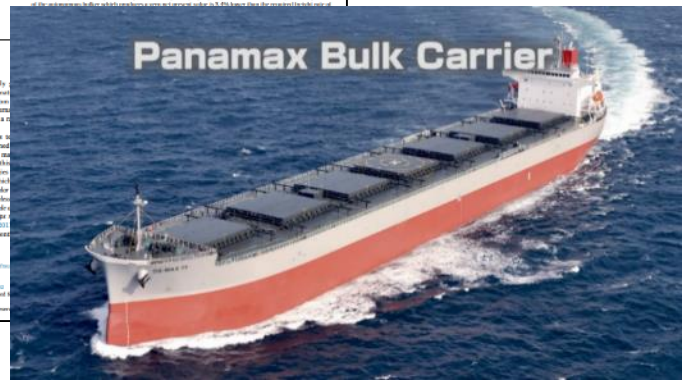
Repair and Maintenance





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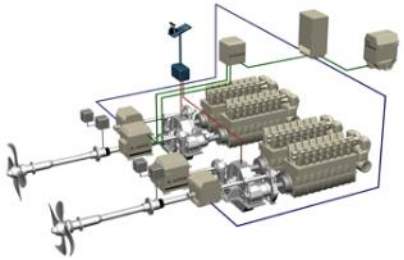

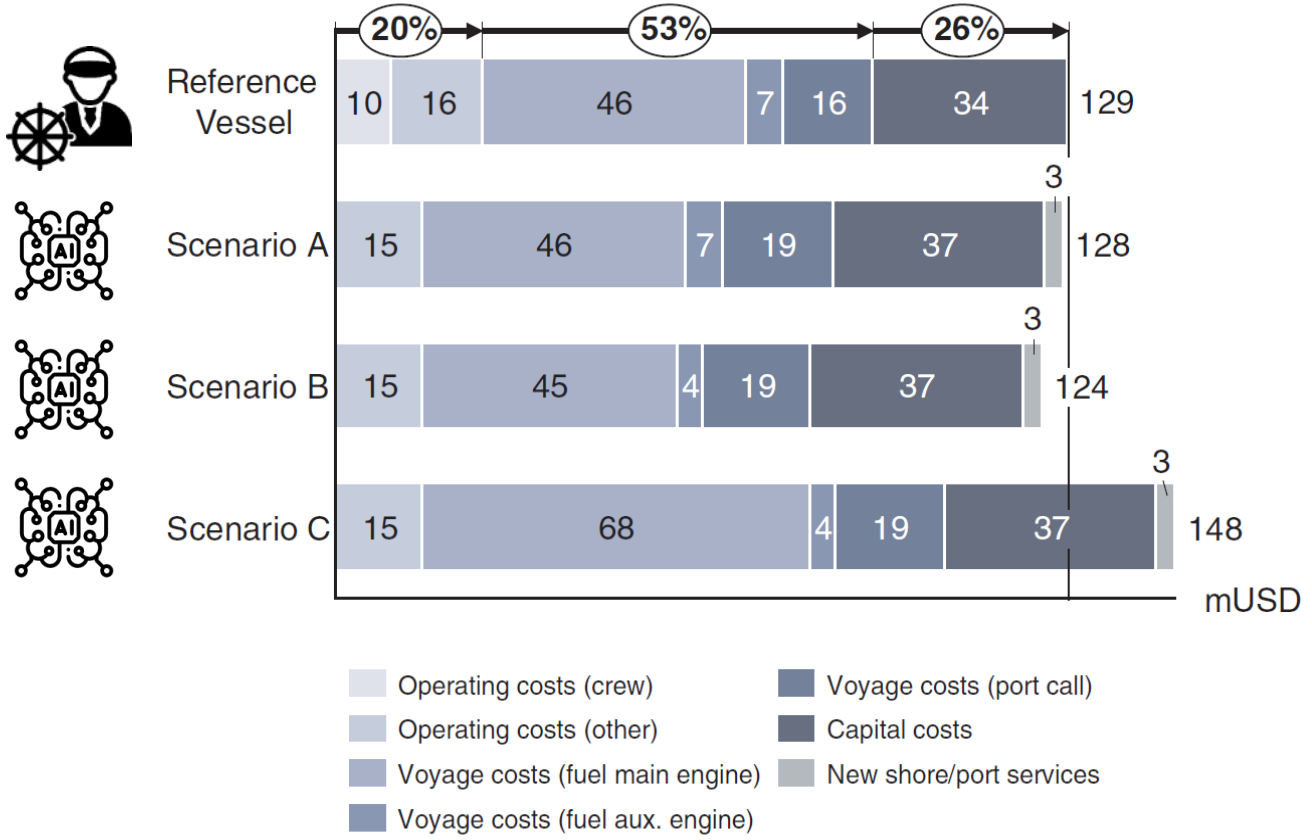

Scenario A: No crew
Scenario B: No crew + Low fuel consumption
Scenario C: Scenario B + High grade fuel

Source: Kretschmann et al. (2017), Analysing the economic benefit of unmanned autonomous ships

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Summary

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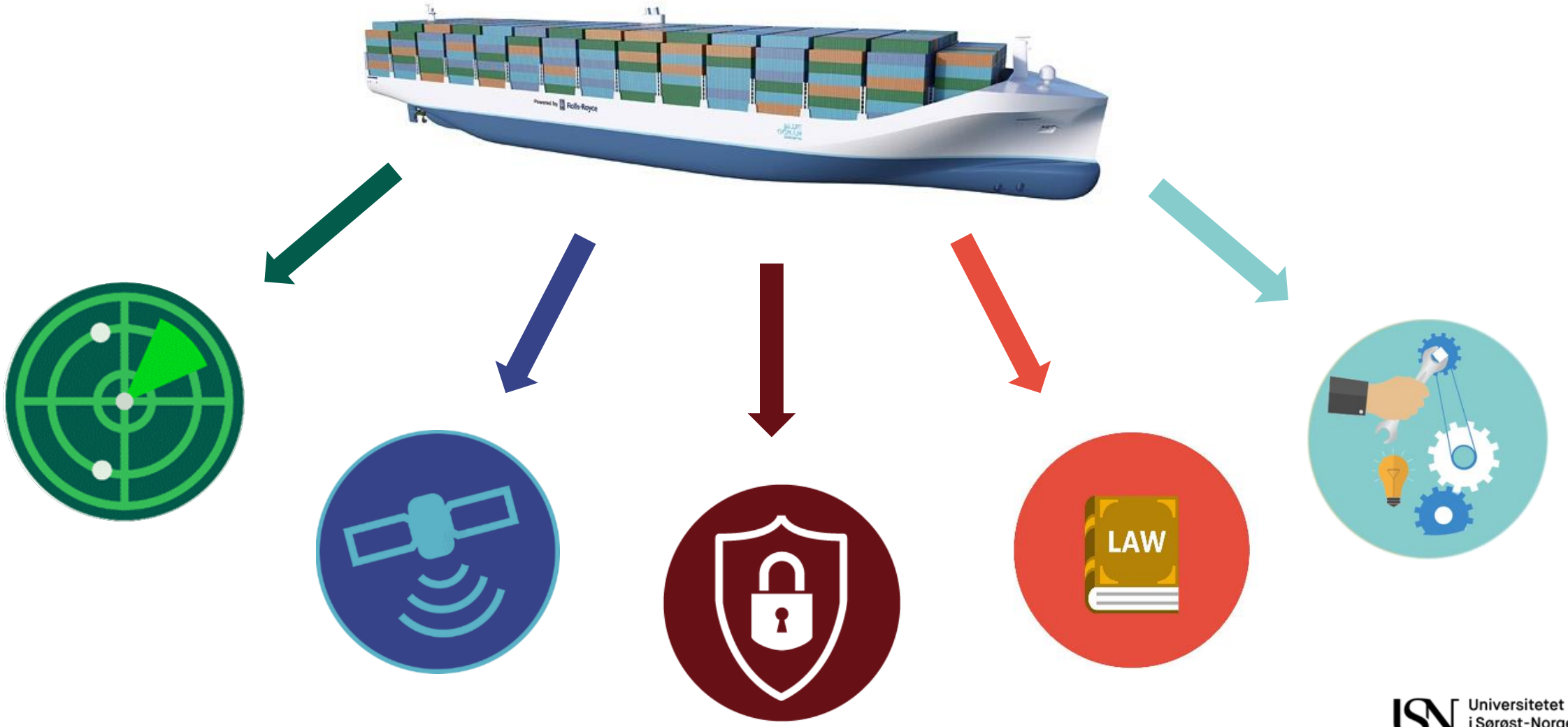
Summary



The Way Forward…



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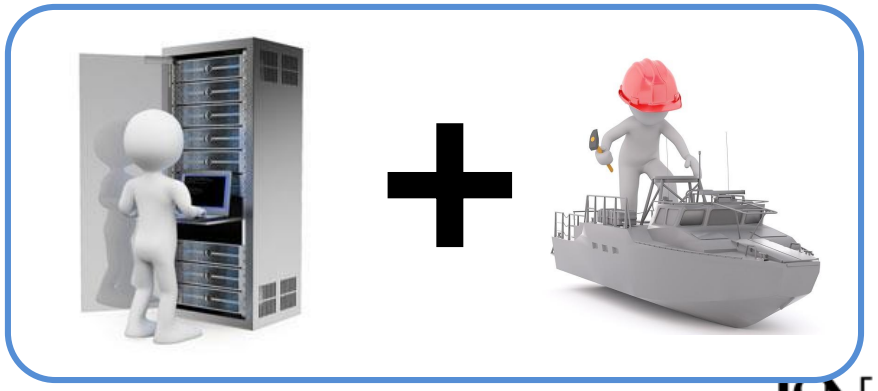
The Way Forward…



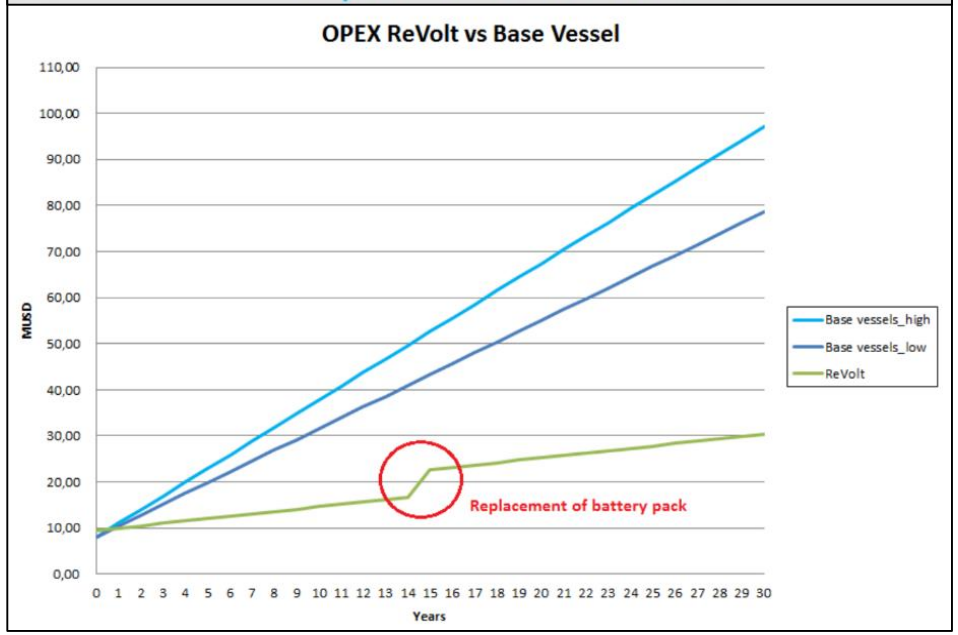






The Way Forward…





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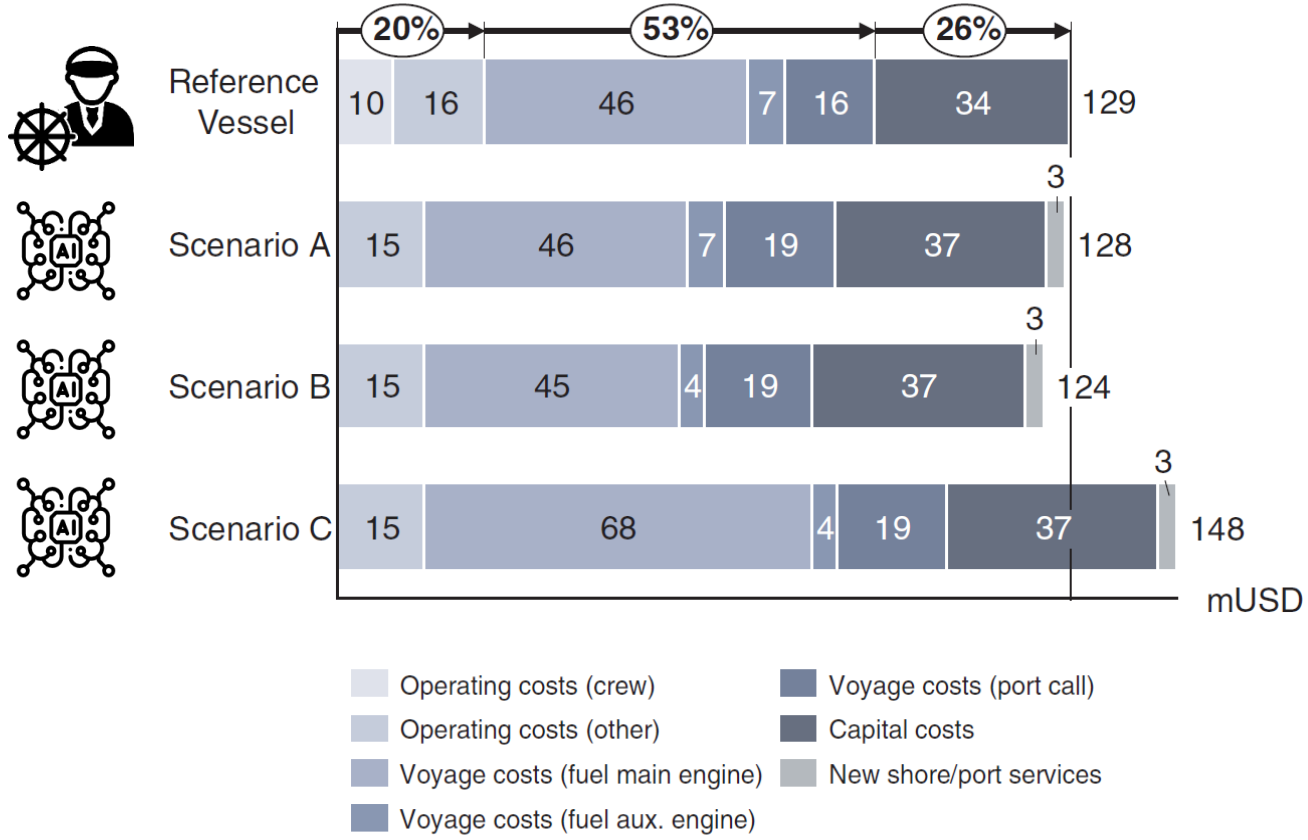

Source: Kretschmann et al. (2017), Analysing the economic benefit of unmanned autonomous ships

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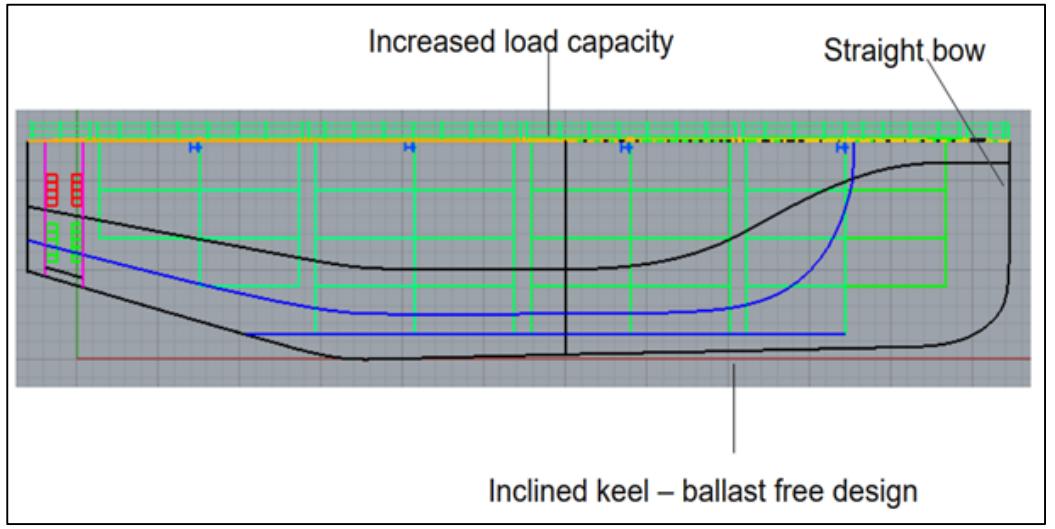
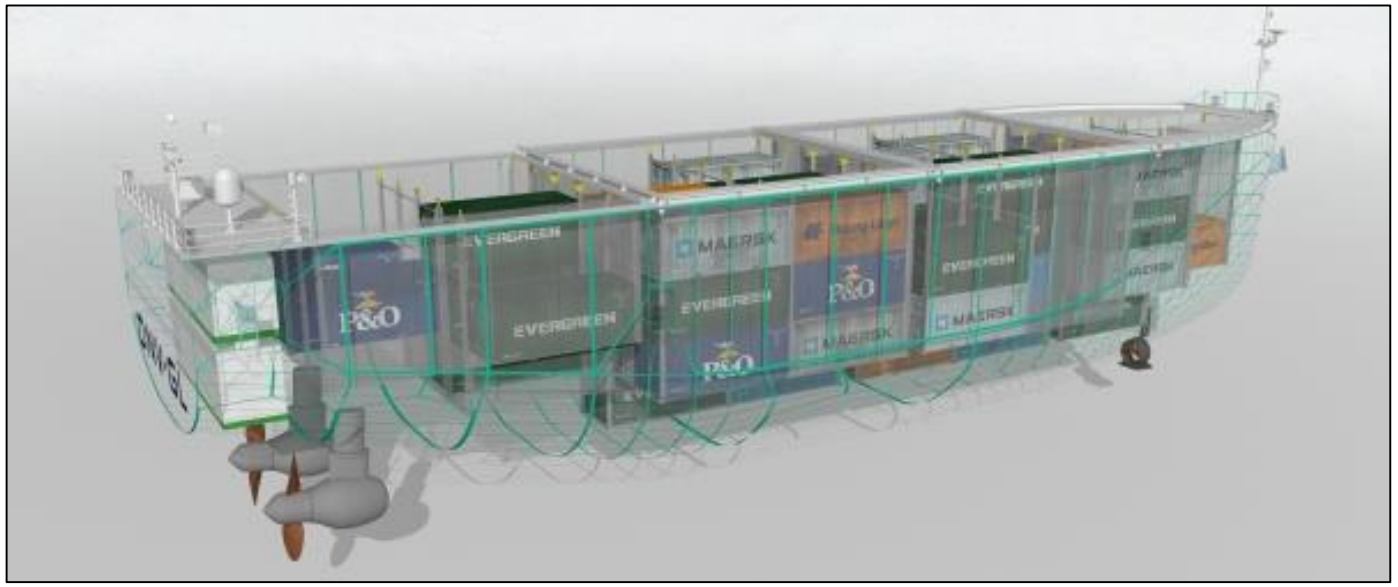
The Way Forward…







Source: SuperyachtNews

The Way Forward…



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