Experiences of main risks and mitigation in autonomous transport systems

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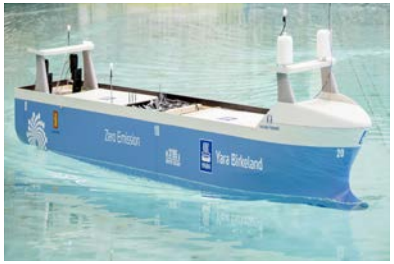
Introduction

1) Approach

– Learn from autonomy across the modes (what may be transferred?)

Sea **Air** **Metro** **Road**




2) Experiences and focus

- ❖ Road (from 2009 – High Focus)
- ❖ Sea (Pilot projects/ ROV/ - High focus)
- – Aviation – UAS (from 1960)
- – Metro systems (from 1980)

3) Research questions

- – Describe major risks introduced
- – how to mitigate the main risks
- – suggest a way forward

Approach and research questions

- Literature review – use, safety and security of unmanned systems
- Interviews of users of autonomous systems (St. Olavs hospital; Metro in Copenhagen, Pilot projects)
- Involvement in regulatory process (Road…)
- Review of research and innovation from the research database of the Norwegian research council – keyword search

Methods

Broad based - Human, Technology and organizational issues (i.e. rules ; regulation;) - Based om Human Factors Analysis and Classification System (HFACS)

- Explore governance and emerging/ new risks … (O. Renn)
- Learn from actual use – practices and incidents
- Assess design and control issues –
  - "Human in the loop challenges" and need for meaningful human control
  - New approaches – i.e. STAMP

Definitions / Terminology

Automated: Deterministic; does exactly what it is programmed to do

Autonomy: A non-deterministic system; freedom to make choices

Levels of automation - Society of Automotive Engineers (SAE):

0-No automation;

1- Driver assistance;

2-Partial automation;

3-Conditional automation;

4-High automation;

5-Full automation

Levels of Automation

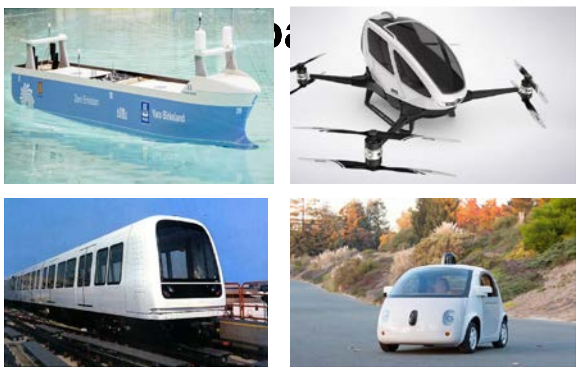
Automotive SAE Levels	Railways Grades of Automation	Aircraft Levels of Automation	Driver Resp.	Vehicle Resp.
L0 No automation ABS, stability control	GoA-0 Sight train operation	Level 1 – Raw data, no automation at all	All	Warns Protects
L1 Driver Assistance Park assist Cruise contro	GoA-1 Manual train operation Automated Train Protection	Level 2 - Assistance Flight director Auto-throttle	Drives	Guides Assists
L2 Partial Automation (longitudinal & lateral) Traffic jam assist	GoA-2 Semi-automatic train operation (STO) Automated Train Op (ATO)	Level 3 – Tactical use. Autopilot (CWS)	Monitors all time	Manage movement within limits
L3 Conditional Automation Highway traf. jam system	GoA-3 Driverless train operation (DTO) Automated train control (ATC) Some control by attendant: operating doors, emergencies	Level 4 – Strategic Flight management system	Ready to take back control	Drives itself but may give back control
L4 High Automation (specific use cases) Valet parking		Uninterruptible auto-pilot project (Boeing) Drones (unmanned)	May not take back control	Drives itself with graceful degradation
L5 Full Automation (all situations)	GoA-4 Unattended train operation (UTO) Automated Doors Platform screen doors		Not required	All time

Table 1: Comparison of automation levels in automotive, railways and aeronautics.

Autonomy – look at the whole system

The system (Power plant/Sensors/…)

Sea **Air** **Metro**



External control

Interaction and communication with other actors

Industrial use– slowly emerging

Replacing dangerous, dirty operations

– moving from remote operation to more unmanned

- Cinematography and aerial photography
- Speedy delivery of critical supplies - (Blood in Rwanda from 2016)
- Inspection of equipment (to avoid dangerous work/ improve quality)- power lines/ storage tanks/ Flame towers (oil and gas)
- Monitoring and surveying road transport/ farmland/ seaways/ borders/ sea /Ice monitoring/ oil spill management
- Illicit transportation (Smuggling)
- Disaster support (overview/ find people/ deliver critical equipment/)
- Fire-fighting (overview, deliver water/ Chemicals close to fire)

–UAS air: less “focus” and projects than in road and sea (Norway)

Autonomous road transport

St Olav: Automated Guided Vehicles (10 years experiences 24 AGV)

- No statistics – but no serious accidents
- Large infrastructure costs, partly isolated, sensor does not see all
- Two persons in control center to handle deviations, halts, problems, lock situations

Google Cars (and autonomous buses)

- Few incidents – from 2,208,199 km (accident rate 1,36 /million km; that is 1/3 of accidents with drivers)
- New kind of accidents: "rage against the machine",
- Human "take over time" – varies from –2 to 26 seconds –design challenges
- Risks: Probabilities reduced/ Consequences higher

Influence of Infrastructure/training: Norway 3 fatalities pr. bill. km – USA 7,3 fatalities

Unmanned metro - from 1980 – no incidents

Rail/Metro

- 48 lines in 32 cities, 674km
- Isolated from others
- Unmanned but operated from control centers

- No known accidents/ incidents
- Poor/ No reporting of incidents
- Based on experiences – probabilities low/ consequences?

M1 & M2 Nørreport, 2013 © R. Schwandl

Manned & Unmanned Aircraft Systems (UAS)

Manned aviation (highly automated but human-in-the-loop)

- "Ultra high safety" – None IATA accidents 2012 & 2017
- More automation but need "Human In the Loop" – when automation cannot cope
- New accidents due to automation - Boeing Max

Unmanned Aircraft Systems (UAS)

- From large "industrial drones" (DoD):
  - DoD UAS: **50-100** incidents for each 100,000 flight hours vs DoD pilot - 1 incident pr 100,000 flight hours
  - DoD – UAS: Poor Human Factors design of control systems

- **MTBF** – 1,000 hours between failures - **100 times more** than in aviation

Unmanned Aircraft Systems (UAS)

Distribution of 1000 failures/accidents (safety)

- Power plant (411) failure; Ground Control system (273); Navigation system (146)
- Electronics (67); Mainframe (54); Payload (53)

Type of accidents

- Loss of control; UAS Crash/ fall down- and consequences of impact
- Collision with regular flights; Ignition of gas ; New types of accidents

Security issues

- Take over control - GPS spoofing (Iran landed USA drone) , Backdoor (Boeing 787)
- Drone Crash/Collision (hacking/DoS)
- Loss of communication – lock out user/ manipulate video control
- Loss of data (pictures, video) – (data may be stored elsewhere - China/USA…)
- Halt/Impact regular air transport
- Illicit transportation /Smuggling (across borders/ to prisons)
- Drone attacks cheaper – critical infrastructure (i.e. As in Saudi-Arabia 2019)

UAS Risks as Likelihood and Consequences

Likelihood - Higher (dependent on operation and procedures)

- +Immature technology – MTBF (100 times) higher than manned aviation
- New issues, Need more data related to safety
- -Replace operations with higher likelihood of accidents / Dangerous operations

Consequences – Lower

- -Replacing dangerous, dirty work - Removing exposure of human pilots/actors
- -More resilient design – parachute; UAS 16 motors –(less single point of failure)
- -Less risk of fire (Batteries – no fuel & ATEX certification)
- Less weight and impact consequences (but dependent on weight/ height/speed ...) falling drone: – 1% risk of fatality (250 gr) – 50% risk of fatality (600 gr)
- New consequences

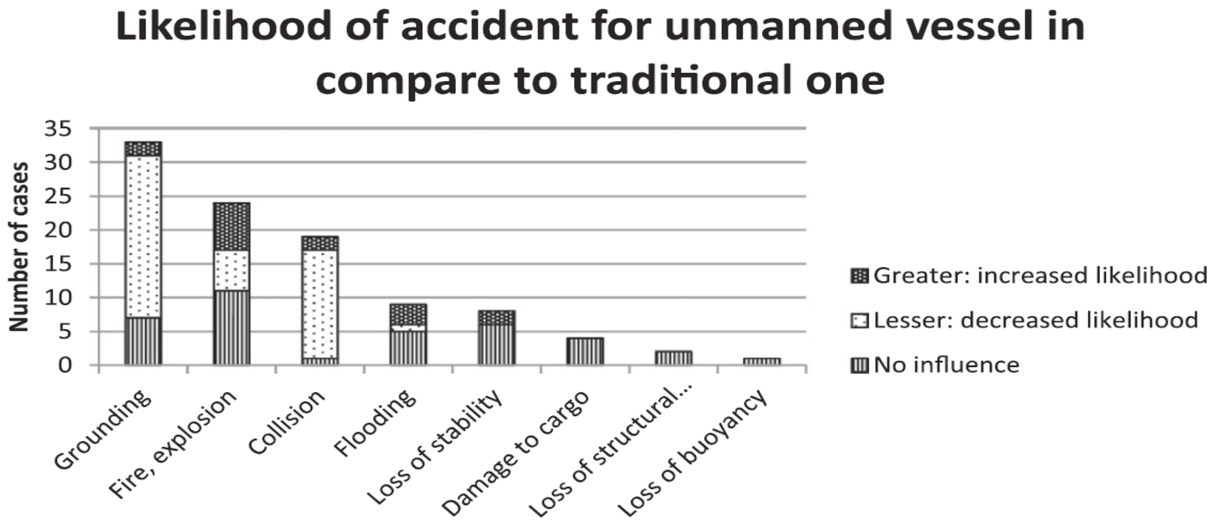
Depends on Operational Design Domain- (ODD) – what/where/how

Autonomous shipping

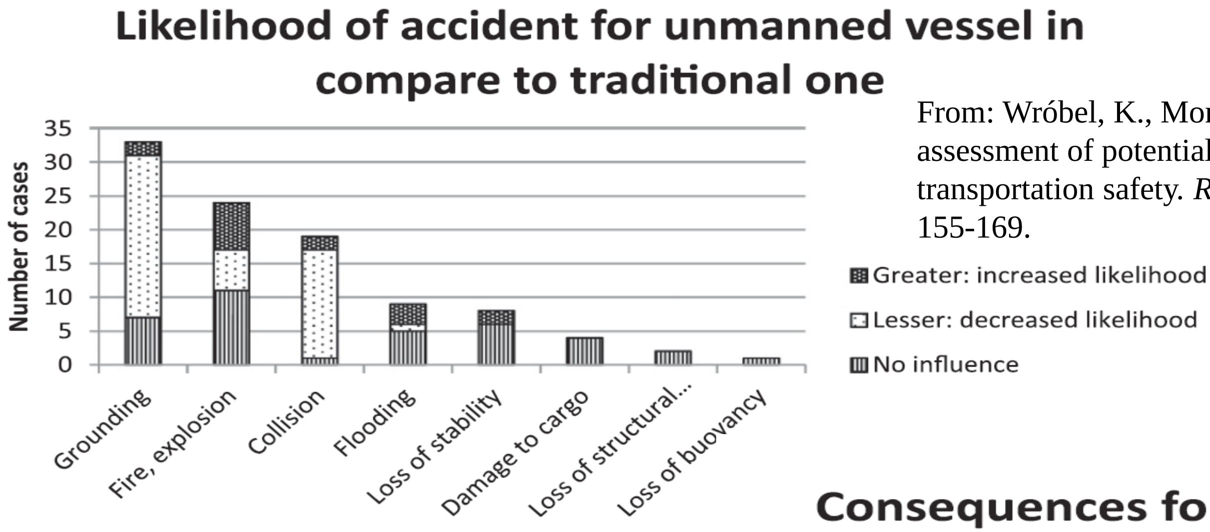
Three testing areas in Norway (six in the rest of the world)

- Yara Birkeland from 2020: 75 meters; 150- containers(removing ~ 40.000 trucs/ year) – gradually implementing autonomy
- Pilots: “Plaske”/AutoFerry – unmanned ferry in Trondheim from 2020;
- Experience from unmanned ferries – incidents with too high load

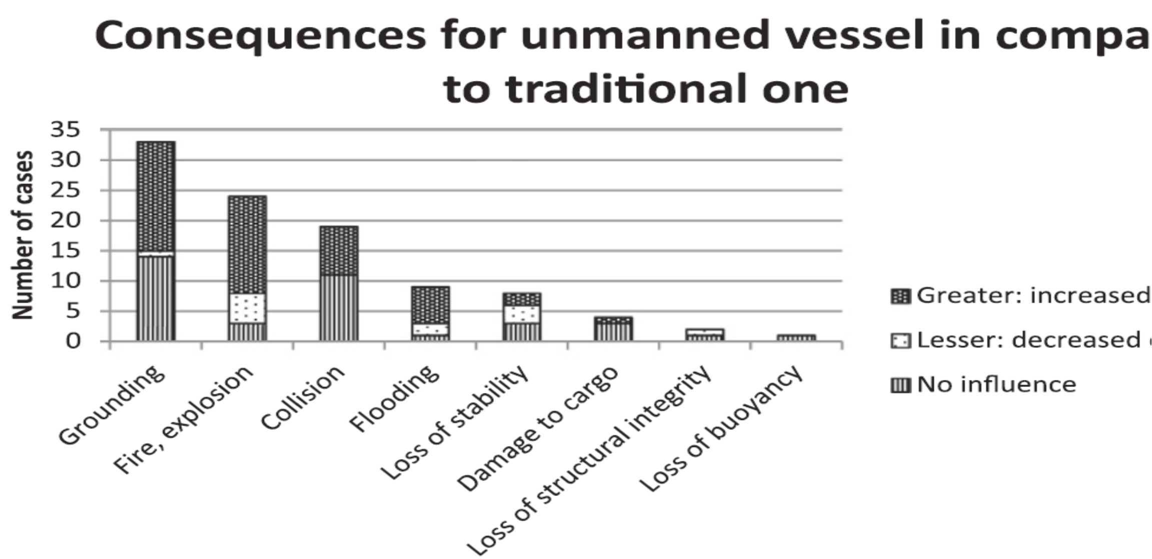
Likelihood of accidents - probabilities



Likelihood of accidents - risks



From: Wróbel, K., Montewka, J., & Kujala, P. (2017). Towards the assessment of potential impact of unmanned vessels on maritime transportation safety. *Reliability Engineering & System Safety*, *165*, 155-169.



Existing UAS Research in Norway

Increasing research - funded by Norwegian Research Council

- 2008-2012: 3,6 Mill EUR
- 2013-2017: 5,7 Mill EUR
- 2018-2021: 12 Mill EUR

Areas of focus

- Maritime/offshore research – Ice monitoring/ UAS heavy load transport/ Remote operations of fish farms
- Technology improvements – Better motors/ batteries; Better control systems (Air traffic)
- Improvements of use (Inspection Power lines/ Bridges; control buildings)

Missing areas

- Improved safety (improved MTBF); Security; Resilience
- Human Factors issues in interfaces / Meaningful human control
- Best practices of procedures, risk assessment, local rules, and regulations
- Societal and ethical issues

Conclusions

Main challenges and benefits

- Immature – need to be industrialized – improved MTBF needed
- May reduce human exposure in dangerous operations

More knowledge and research needed

- Systematic learning from operations and incidents
- More pilot projects in critical areas to speed up learning and development
- Meaningful human control a key issue – design of interaction and control centres
- Certification schemes to raise quality, human factors issues, safety, security
- Expert group of regulators, industry users, operators and developers should work together to speed up development of systems, regulation and best practices (i.e. risk assessments) to reach high level of safety, reliability, resilience and security
- Security issues ?