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A TAXONOMY FOR AUTONOMOUS VEHICLES FOR DIFFERENT TRANSPORTATION MODES

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Introduction

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- Autonomous ships received much interest in the last few years after the presentation of the worlds first autonomous unmanned container of Yara Birkeland

- Ships are not the first ones to become autonomous!

- Autonomous transport vehicles needs to satisfy a common criterion SAFETY

Safety requirements for different vehicles

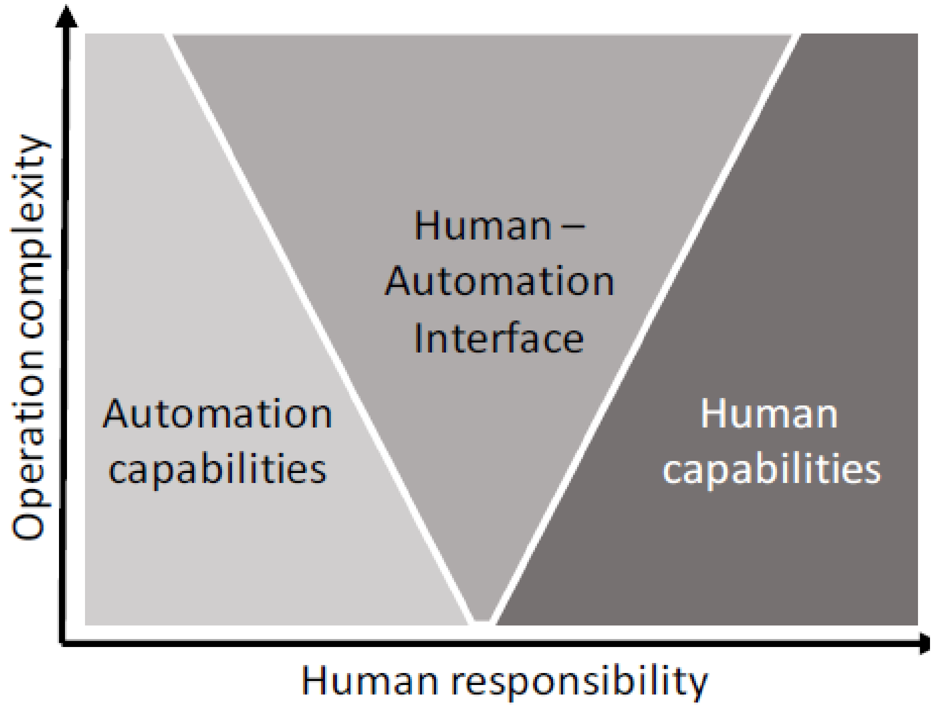
- Different classes of vehicles can have significant differences regarding their safety requirements

Means of transport	Characteristics
Ships, Light trains, Airplanes	Large systems with high value which are often supervised from a remote control centre and authorities
Cars	Intervention of the driver no control centre, no authority surveillance
Busses	They lay somewhere in between

- The potential damage is also very different with inherently close to negligible for small underwater craft to very high for fast moving autonomous cars in mixed traffic.

Levels of Autonomy and safety in autonomous systems

- Most classifications of levels of autonomy (LoA) look only on the division of responsibility between human and automation
- The focus on responsibility divisions is natural as the Human-Automation Interface (HAI) may be a significant source of safety hazards in operation of semi-autonomous systems



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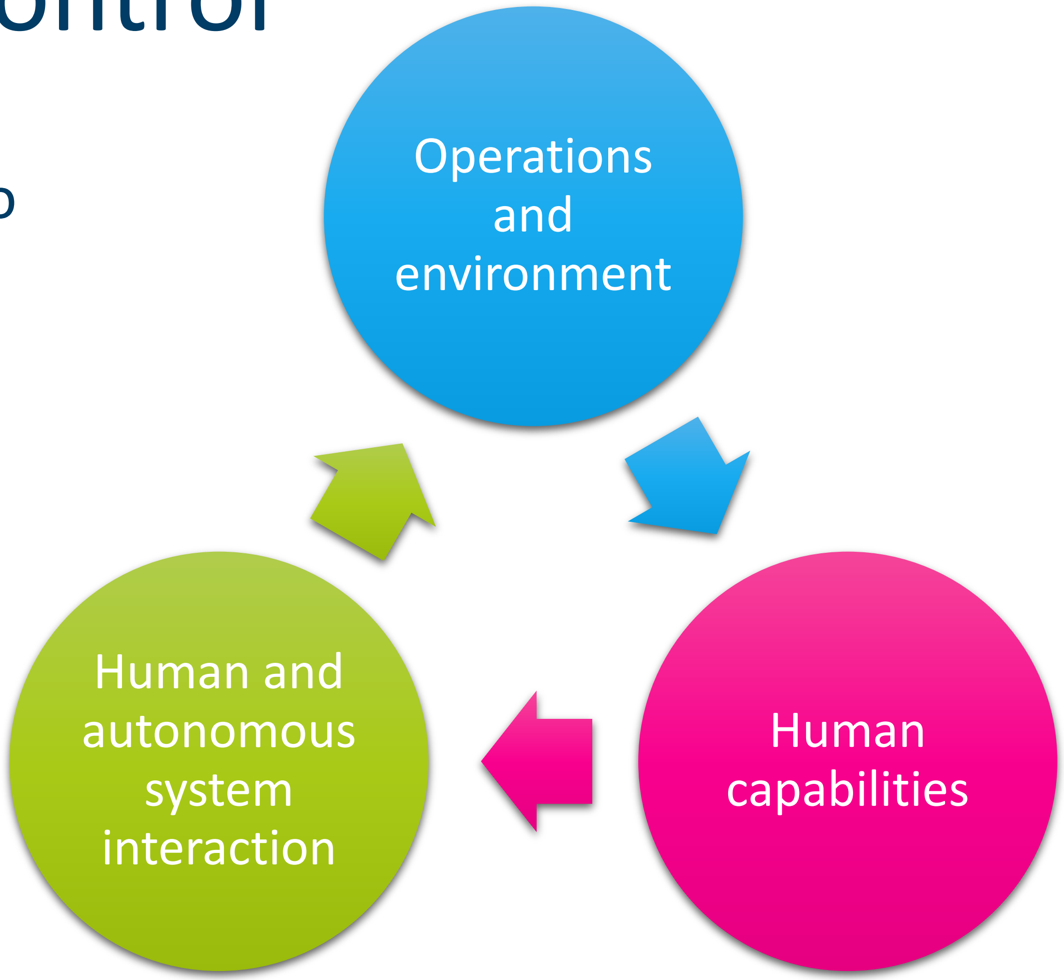
Hazard types to be considered in autonomous systems and control

a) The capabilities of the automation system to handle all relevant problems in the operations and environment

b) The capabilities of the human to handle any tasks that are delegated to the operator

c) How well human and autonomous systems can cooperate with each other.



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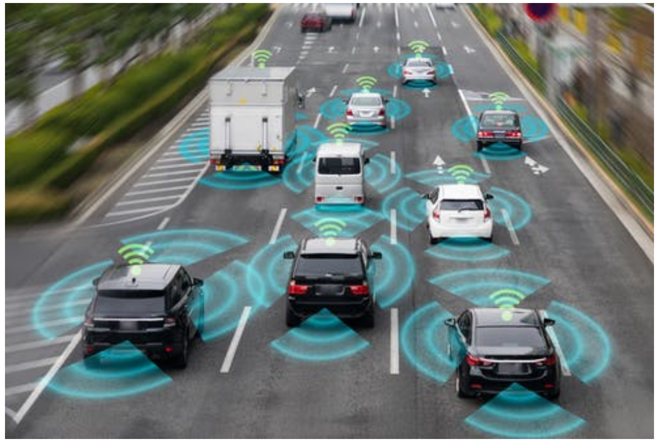
Autonomous cars



- *"Autonomous cars seem like a promise that is here, almost here, and still not happening for years and years"*
- Different questions have been raised after the last accidents that have caused the death of pedestrians
- The public started again being sceptic about them.

Autonomous cars

The main challenges

- cars' safety when perception and decision-making capabilities are concerned.
- how to build an autonomous car that will have a better perception of the road than the best human driver has.
- Usefulness *" I can be completely safe if I don't drive or if I drive very slowly, but then I'm not useful, and society will not want those vehicles on the road"*
- Cost-effectiveness, so consumers are willing to switch to driverless.
- Ability to handle extreme and unexpected events including their moral aspects

Autonomous cars LoA

- Six levels of autonomy are proposed by NHTSA for autonomous cars as they are presented below.

Level of Autonomy	
LoA0	No automation. Zero autonomy, the driver performs all driving tasks.
LoA1	Driver assistance. Vehicle is controlled by the driver, but some driving assist features may be included in the vehicle design.
LoA2	Partial Automation. Vehicle has combined automated functions, like acceleration and steering, but the driver must always remain engaged with the driving task and monitor the environment.
LoA3	Conditional Automation. Driver is a necessity, but it is not required to monitor the environment. The driver must always be ready to take control of the vehicle with notice.
LoA4	High automation. The vehicle can perform all driving functions under certain conditions. The driver may have the option to control the vehicle.
LoA5	Full automation. The vehicle can perform all driving functions under all conditions. The driver may have the option to control the vehicle.

Light rail/metros

- Possible the easiest means of transport to become autonomous because of their simple and safe environment
- Little amount of them already runs in an autonomous mode
- Challenges
  - Door closure without negatively impacting operations
  - Stopping distance far superior to road systems i.e. for a TGV 300km/h stopping distance is 3000, in emergency break, 9000m in service break, for RER 80km/h 300m in emergency stop, 500m in service break

Light rail/metros LoA

- The most commonly taxonomy used for these types of autonomous systems consists of 5 levels of autonomy and is described as follows

LoA	Description
LoA0	No automation
LoA0+	The system controls the speed.
LoA1	The system allows for a movement authority and a requested speed profile. External systems can detect non-railway related risks (lateral winds) and the modification of speed is communicated to the driver by these systems.
LoA2	Operation system is interfaced with the onboard and ATP/supervisor equipment. The speed modification is communicated by the non-railways risk detection systems to the ATO.
LoA3	The driver becomes an on-board attendant and intervenes only when necessary.
LoA4	The train drives itself without the presence of an onboard agent.

Trams

Trams operate in less controlled environments, with traffic and passengers

Challenges

- Limited market compared to R&D costs
- Additional complexity in security validation if Deep Learning is used (opacity of the algorithms, error rate, incompleteness of data, instability).
- Tradeoff between safety and availability of the service/overall performance of the system
- The stopping distance that is required that is far superior than road vehicles (wheel rail contact and no belted passengers): 50 km/h, stopping distance: 100 m, which is 3 times more than that for a car.
- Departure of the train in the station with the presence of many pedestrians in front of the train.

Trams LoA

- Commonly 5 LoA are proposed when it comes to tram systems

LoA	Description
LoA0	No automation
LoA0+	The system controls the speed (with a gentle and progressive sanction mode)
LoA1	The system helps the driver to drive better (speed setpoint, passive driving aids)
LoA2	The driver assists the system to be driven (control and speed control by the system, acti initiated either by the driver or by the system…)
LoA3	The driver becomes an attendant and intervenes when necessary
LoA4	The tram drives itself, without the presence of any onboard agent

UAVs

- Different approach since they fly in the air but they ARE a reality
- Commercial sales to private people that fly can fly them in different environments
- They can cause damages even to city infastructures
- Not a fully defined insurance scheme available
- Privacy risks to people since they can be used to check into houses or pedestrians walking in the cities

UAVs LoA

- LoA can vary according to the desired application, the area of flight etc. However, NATO WG defines four levels to classify the autonomy of a UAV system and is the one presented below.

LoA	Description
LoA1	Remotely Controlled System - System reactions and behaviour depend on operator input
LoA2	Automated System - Reactions and behaviour depend on fixed built-in functionality (preprogramed).
LoA3	Autonomous non-learning system - Behaviour depends upon fixed built-in functionality or upon a fixed set of rules that dictate system behaviour (goal-directed reaction and behaviour)
LoA4	Autonomous learning system with the ability to modify rules defining behaviors - Behavior depends upon a set of rules that can be modified for continuously improving goal directed reactions and behaviors within an overarching set of inviolate rules/behaviors.

Comparison on LoA for different transport systems

Focus mainly is on safe operation and, e.g. accident statistics is important to reuse over modes, if possible.

Criteria

- HMI
- Environmental Complexity
- System complexity
- Societal acceptance

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HMI

- How the different modes make use of human backup or

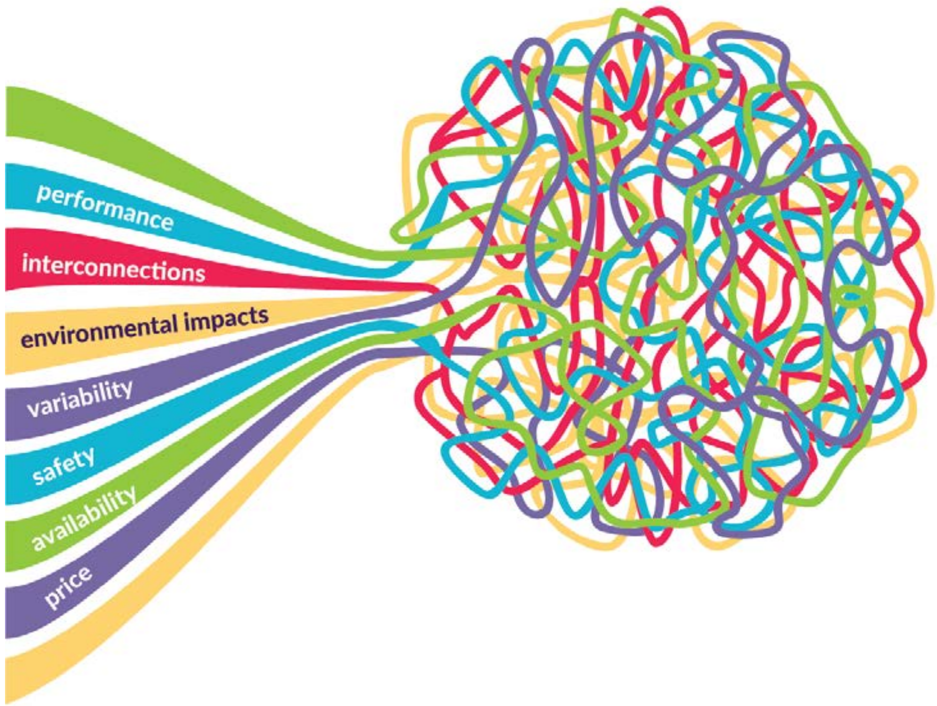
support is a major difference between modes.

- The reasons for this are varied, but some important factors are briefly described below:
    - *Size of vehicle:* High value vehicles tend to be less autonomous than smaller and cheaper vehicles.
    - *Passengers on board: T*rained personnel onboard is needed to handle emergencies and possible evacuations. Safe boarding and disembarking of passengers are also a challenge.
    - *Suitability for good HAI solutions:* The type of interaction between human and automation is also very different between modes.

Environmental Compelxity

- Different systems have different complexity according to the environment they operate.
  - *Object detection complexity*: How easy it is to implement an object detection system? Environmental factors, how dense are the obstacles that need to be avoided, spped of the vehicle speed
  - *Availability of maps*: Can the vehicle rely on a pre-mapped environment or not
  - *Traffic lanes*: The use of defined traffic lanes will also simplify the environment in which autonomous systems operate

System complexity



- Autonomous vehicles vary in complexity.
- The main factors determining system complexity are:
  - *Physical size and complexity:* The larger the vehicle is, the more complex its systems are.
  - *Voyage duration*

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Societal acceptance

- How well the society tolerates the deployment of such vehicles and, any accidents related to the use of the vehicles?
- Societal acceptance is built on several factors
  - *Damage potential – Hazards severity*: A mass-produced autonomous car will have a very high damage potential as several may fail due to, e.g. a systematic error in software. A large ship has a high damage potential, but as there will be relatively few of them and as they generally move in relatively uncluttered environments, it can be characterized as medium to high hazard severity.
  - *Perceived usefulness* for the society at large
  - *Exposure of "innocent" people*
  - *Familiarity to the public*

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Modes comparison

There are significant differences and the one which stands most out may be the autonomous car, due to its possible problem with societal acceptance.

General description	Car	Metro	Truck	Small AV	MASS	IWW
HAI	Shared	Supervised	Supervised	Autonomous	Supervised	Shared
Env. complexity	High	Low	Medium	Medium	Medium	Medium
System complexity	Medium	Medium	Medium	Low	High	High
Societal acceptance	Low	High	High	High	High	High

Conclusions

- Summarizing the characteristics of different transport modes and what level of automation principles they employ.
- Comparing the taxonomy that is commonly used in each different transportation mode. Whats common what not?
- Each mode depends on multiple decisions like the application itself, the environment to be used, the complexity, the security factors and the societal acceptance by the population.

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