AUTONOMOUS VESSEL: STATE OF THE ART AND POTENTIAL OPPORTUNITIES IN LOGISTICS

JULIO C. GOEZ, MARIO GUAJARDO, YEWEN GU AND STEIN W. WALLACE
NORWEGIAN SCHOOL OF ECONOMICS
CENTRE FOR APPLIED RESEARCH AT NHH (SNF)
CENTRE FOR SHIPPING AND LOGISTICS

Challenges for the conventional ships

- 71% of Earth's surface covered by sea
- Most of the world trade is carried by sea
- Only option for large volume cargo transport among continents

Challenges for the conventional ships

- Extremely capital intensive
- Highly volatile (bunker price & freight rate)
- Low margin rate
- Environmental challenges

Challenges for conventional ships

- What can we do?

  - Build ships even larger to have more economies of scale? 
  - Continue to decrease the sailing speed and use slow steaming forever? 
  - Charge all the additional costs to the shippers and act like nothing happened? 

  - Increase *operational efficiency* and decrease the *carbon footprint* through technology and innovation, such as **autonomous ships**

What is an autonomous ship?

Source: MUNIN Project

➢*An Advanced Sensor Module*: takes care of the lookout duties on board the vessels (e.g. radar and AIS, combined with modern daylight and infrared cameras)

➢ *An Autonomous Navigation System*: follows a predefined voyage plan, be able to adjust it in accordance with unexpected incidents (e.g. collision situation or significant weather changes)

➢ *An Autonomous Engine and Monitoring Control system*: ensure the overall reliability and foresee the potential failures

➢ *A Shore Control Centre*: continuously monitors the operations of the autonomous vessel and be prepared to intervene in certain emergencies

Levels of autonomy

AL 0: Mannual steering

AL 1: Decision-support on board

AL 2: Shore-based decision support

AL 3: Execution with human being who monitors and approves.

AL 4: Execution with human being who monitors and can intervene

AL 5: Monitored autonomy

AL 6: Full autonomy

Description	Operator role
AL 0: Manual steering. Steering controls or set points for course, etc. are operated manually.	The operator is on board or performs remote control via radio link.
AL 1: Decision-support on board. Automatic steering of course and speed in accordance with the references and route plan given. The course and speed are measured by sensors on board.	The operator inserts the route in the form of "waypoints" and the desired speed. The operator monitors and changes the course and speed, if necessary.
AL 2: On-board or shore-based decision support. Steering of route through a sequence of desired positions. The route is calculated so as to observe a wanted plan. An external system is capable of uploading a new route plan.	Monitoring operation and surroundings. Changing course and speed if a situation necessitates this. Proposals for interventions can be given by algorithms.
AL 3: Execution with human being who monitors and approves. Navigation decisions are proposed by the system based on sensor information from the vessel and its surroundings.	Monitoring the system's function and approving actions before they are executed.
AL 4: Execution with human being who monitors and can intervene. Decisions on navigation and operational actions are calculated by the system which executes what has been calculated according to the operator's approval.	An operator monitors the system's functioning and intervenes if considered necessary. Monitoring can be shore-based.
AL 5: Monitored autonomy. Overall decisions on navigation and operation are calculated by the system. The consequences and risks are countered insofar as possible. Sensors detect relevant elements in the surroundings and the system interprets the situation. The system calculates its own actions and performs these. The operator is contacted in case of uncertainty about the interpretation of the situation.	The system executes the actions calculated by itself. The operator is contacted unless the system is very certain of its interpretation of the surroundings and of its own condition and of the thus calculated actions. Overall goals have been determined by an operator. Monitoring may be shore-based.
AL 6: Full autonomy. Overall decisions on navigation and operation are calculated by the system. Consequences and risks are calculated. The system acts based on its analyses and calculations of its own capability and the surroundings' reaction. Knowledge about the surroundings and previous and typical events are included at a "machine intelligent" level.	The system makes its own decisions and decides on its own actions. Calculations of own capability and prediction of surrounding traffic's expected reaction. The operator is involved in decisions if the system is uncertain. Overall goals may have been established by the system. Shore-based monitoring.

Source: Blanke et al., 2017

Motivation

- The technologies needed for an autonomous vessel are almost there, which leads to an increasing interest about this new concept in both academia and industry.

- Several review papers about autonomous vessels are found, e.g. Campbell et al. (2012); Liu et al. (2016); Thieme et al. (2018). But all of them only focus on a very specific topic, such as collision avoidance systems

- No comprehensive literature review is made for all different types of papers related with autonomous vessels

Purpose

- Search and collect all research papers about autonomous vessels and categorize them based on their content
- Summarize the major findings in each category
- Analyze the literature according to several criteria and conclude on the current status of autonomous vessel related research
- Compare with the literature of autonomous vehicles to find the weak point and future opportunities of the studies of autonomous vessels

Methodology

- Main search engine: Scopus
- Language: English
- Paper type: journal article, book chapter, important project report
- Search key words: Autonomous ship, Autonomous vessel, Unmanned surface vehicle, Autonomous surface vehicle

Methodology

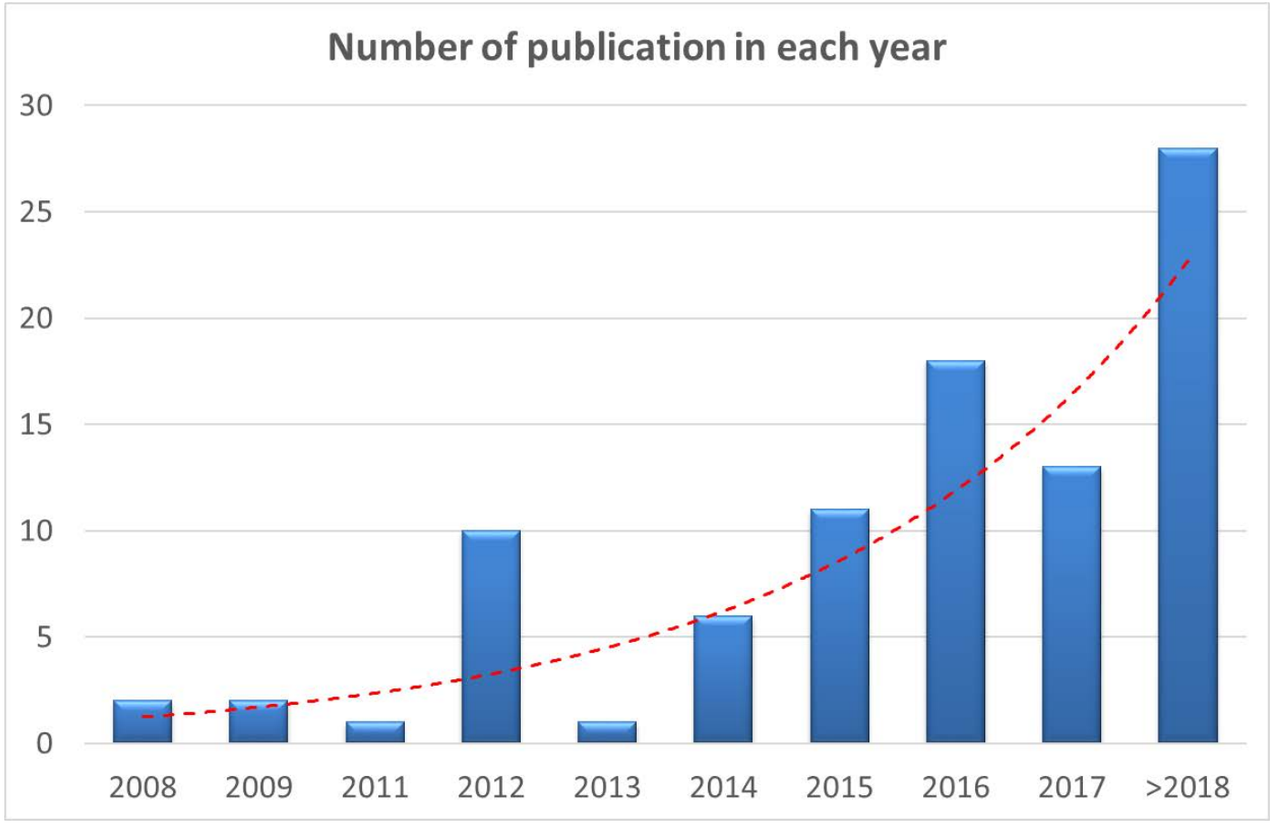
- Nine categories and example topics:

1. Safety
   - *Cyber security*
   - *Collision avoidance*
2. Navigation Control
   - *Trajectory planning*
   - *Maneuvering*
   - *Formation*
3. Design
   - *General design*
   - *Sub-systems*
4. Project & Prototype
   - *Major research projects, e.g. MUNIN*
   - *Experimental prototypes*
5. Economics
   - *Cost-benefit analysis*
6. Social Impact
   - *Environment*
   - *Emission reduction*
7. Law & Regulation
   - *Maritime law*
   - *Accident liability*
8. Transportation & Logistics
   - *Impact on shipping*
   - *Application in transportation*
9. General Introduction of Autonomous Vessel

Results

- Qualified papers: 92
- Countries and regions involved: 27
- Journal and publishers involved: 41
- Time span: 2008 - 2018

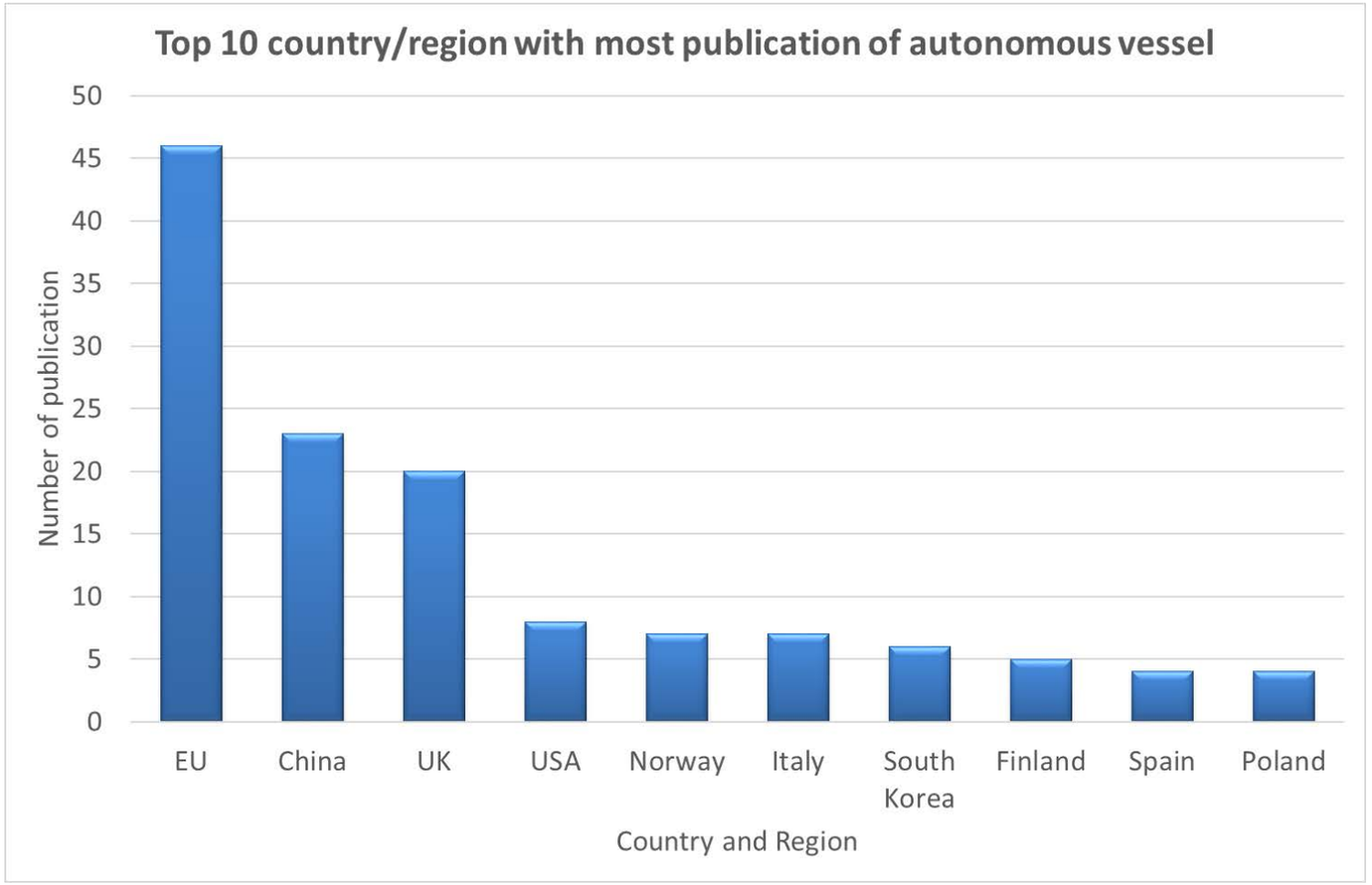
Results



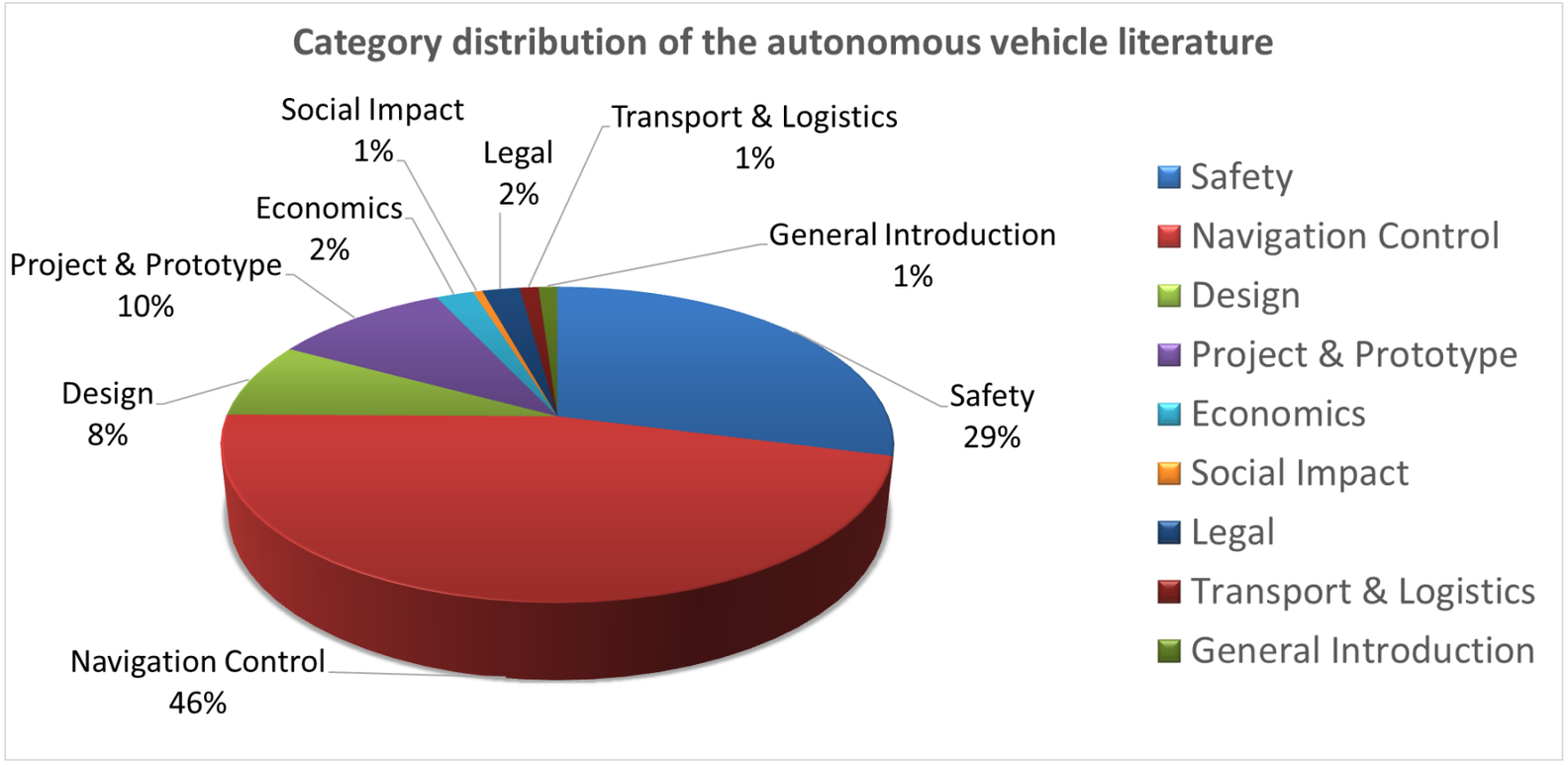
- The popularity of research regarding autonomous vessels has increased rapidly in the past decade

Results

- Studies of autonomous vessels are most developed in EU, China, USA and Norway



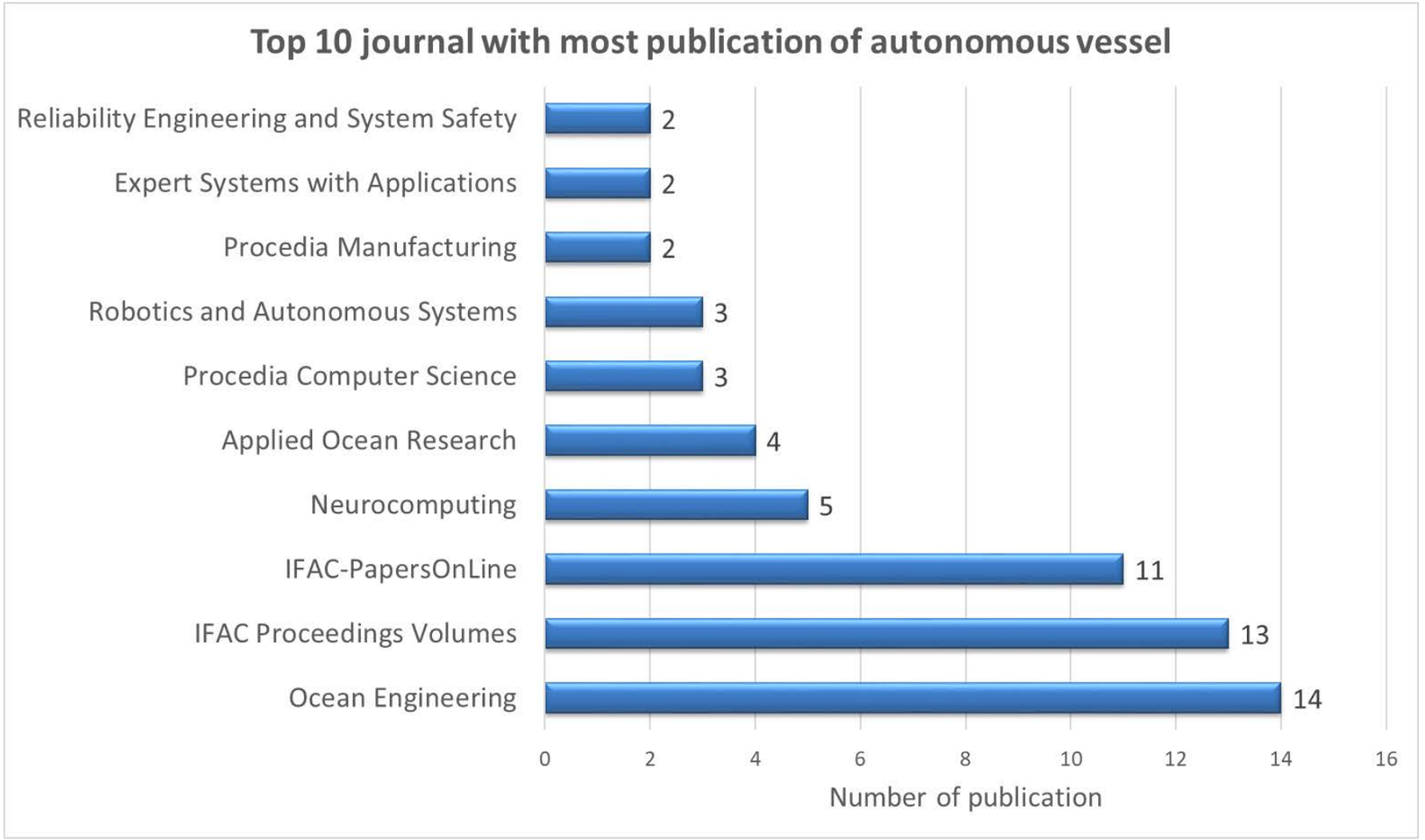
Results



- Around 75% of the papers in the current literature about autonomous ships are related with Navigation Control and Safety
- Other categories are much less studied

Results

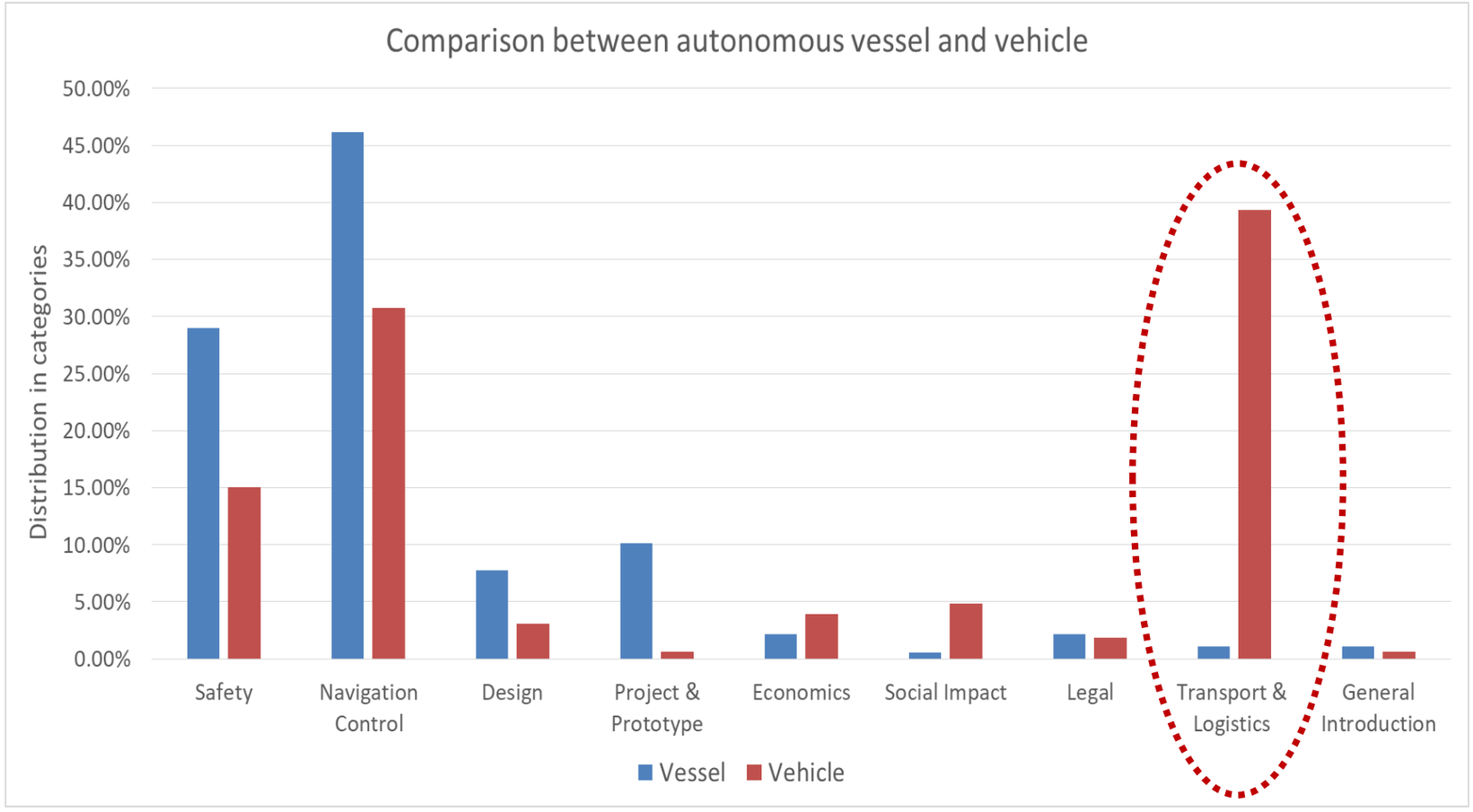
- The observed category distribution coincides with the top journals with most publication of autonomous vessel
- Most of the papers are published in engineering related journals



Results

- Comparing with the literature on autonomous vehicles
  - Main search engine: Scopus
  - Language: English
  - Paper type: journal article
  - Search key words: Autonomous vehicle, Autonomous car, Automated vehicle, Automated car, Automated driving
  - Time span: 2015 – 2018 (due to the large amount of papers)
  - Papers found: 161

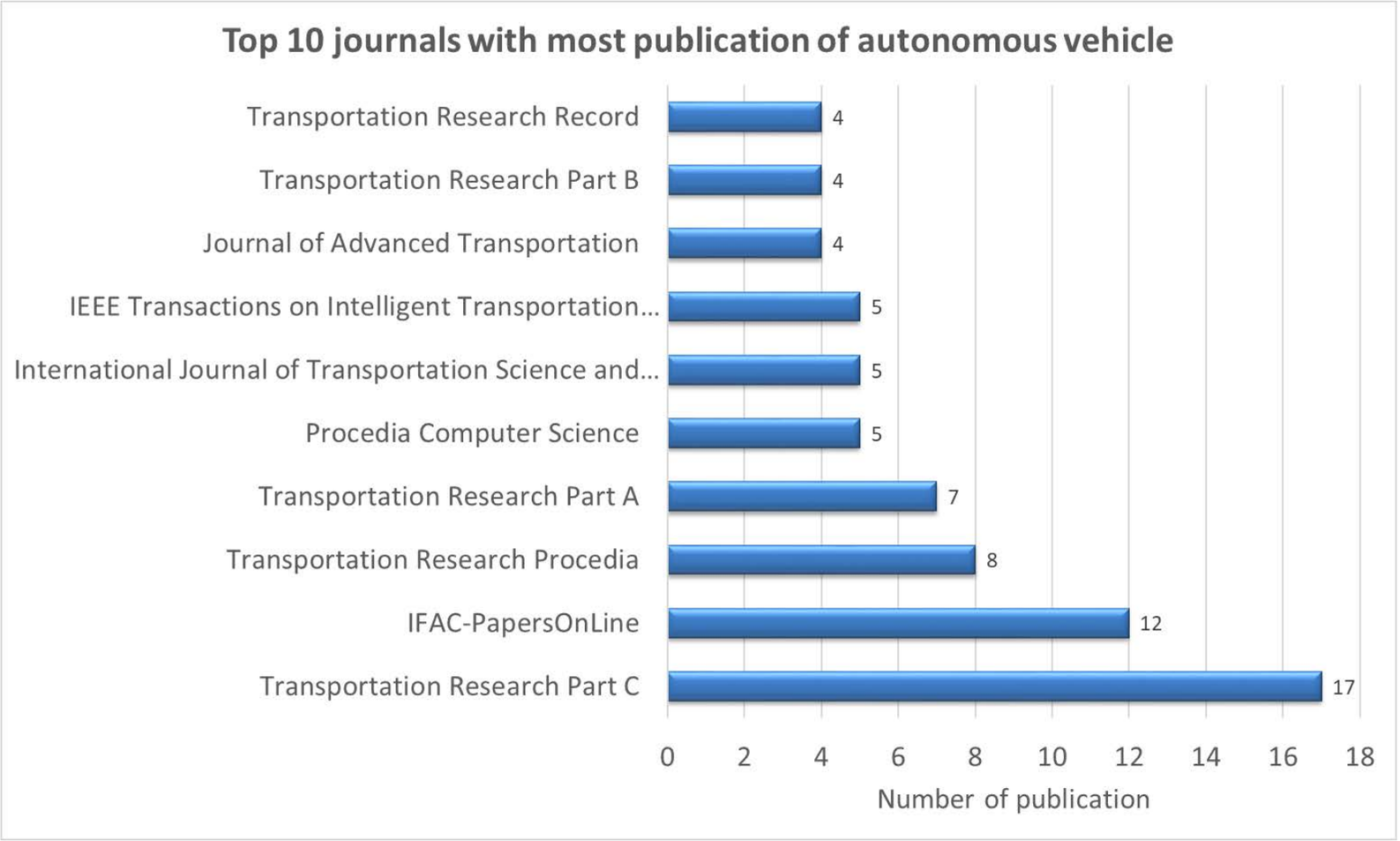
Results



- Similarly, Safety and Control are still very important topics in the literature on autonomous vehicles
- But the most popular area of autonomous vehicle study is transport and logistics

Results

- Transportation related journals published most of the papers related with autonomous vehicles



Results

- Typical topics in the transportation and logistics related papers of autonomous vehicle:
  a. Shared economy in transport with autonomous vehicle
  b. Automated taxi
  c. Last mile problem with autonomous vehicle
  d. Routing and speed optimization of autonomous vehicle

Examples in logistics with autonomous vehicle

European Journal of Operational Research 000 (2018) 1–0

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Innovative Applications of O.R.

Scheduling last-mile deliveries with truck-based autonomous robots

Nils Boysen[a,1,*], Stefan Schwerdfeger[b], Felix Weidinger[a,1]

[a] *Lehrstuhl für Operations Management, Friedrich-Schiller-Universität Jena, Carl-Zeiß-Straße 3, Jena 07743, Germany*
[b] *Lehrstuhl für Management Science, Friedrich-Schiller-Universität Jena, Carl-Zeiß-Straße 3, Jena 07743, Germany*

Examples in logistics with autonomous vehicle

Fig. 1. Truck-based autonomous robots. Source: Daimler https://www.daimler.com/innovation/specials/future-transportation-vans/.

Examples in logistics with autonomous vehicle

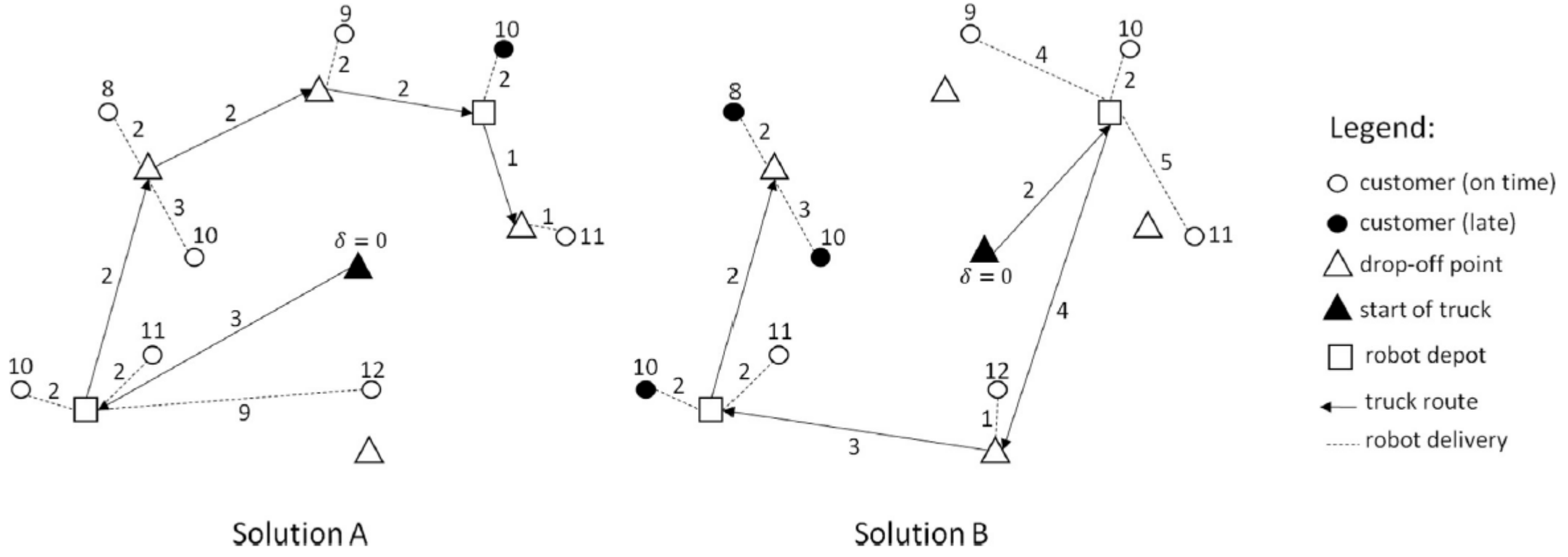


Fig. 2. Two alternative solutions for an example instance of TBRD.

Examples in logistics with autonomous vehicle

Transportation Research Part C 102 (2019) 370–395

Contents lists available at ScienceDirect

Transp

journal hon

ELSEVIER

Autonomous shuttle bus servic using skip-stop tactic

Zhichao Cao[a,b], Avishai (Avi) Ceder[b,c,

[a] School of Transportation and Civil Engineering, Nantong Universit
[b] Transportation Research Centre, Department of Civil and Environ
New Zealand
[c] Faculty of Civil and Environmental Engineering, Technion – Israel
[d] International Development and Cooperation (IDEC) at the Hiroshi

Transportation Research Part E 93 (2016) 115–129

Contents lists available at ScienceDirect

Transportation Research Part E

journal homepage: www.elsevier.com/locate/tre

ELSEVIER

Optimizing the service area and trip selection of an electric automated taxi system used for the last mile of train trips

Xiao Liang *, Gonçalo Homem de Almeida Correia, Bart van Arem

Department of Transport & Planning, Delft University of Technology, Delft, The Netherlands

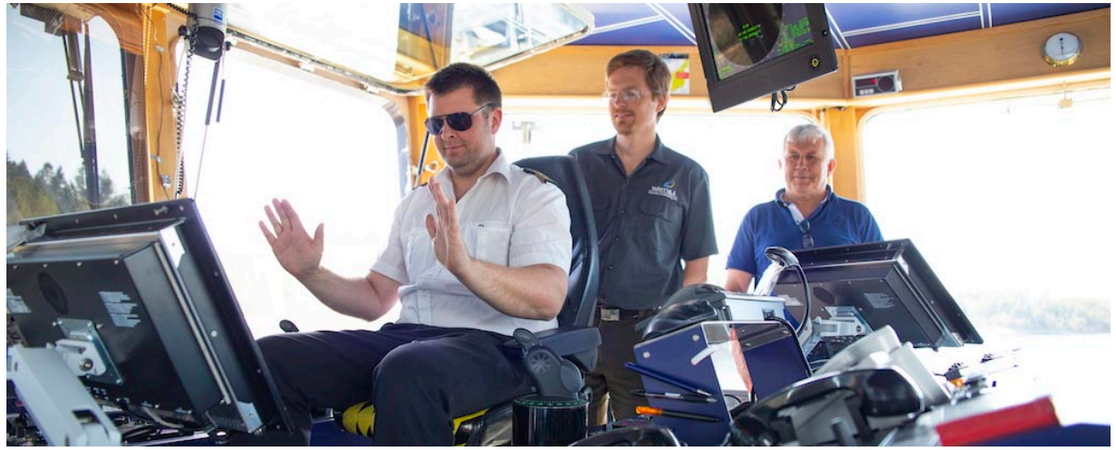
Analysis

Source: http://fortune.com

Source: http://fortune.com

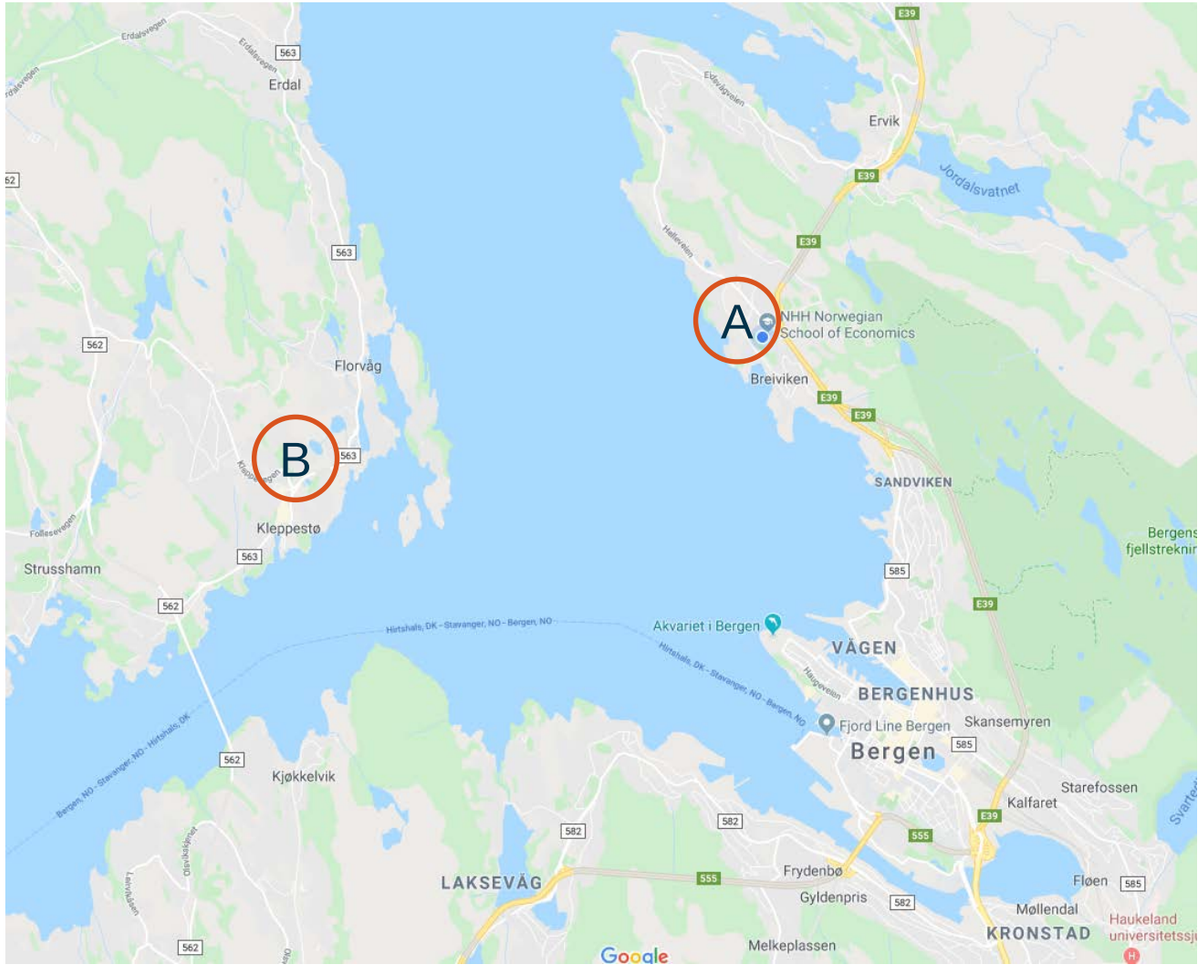
Analysis

Source: yara.com



Source: wartsila.com

Water taxi in Bergen



- A to B by car – 20 km & 30 mins
- A to B by bus – 60 mins
- A to B by boat – 3 km & 10 mins
- Big potential for urban water transport

Water taxi in Bergen

Disadvantage of manned water taxi	Advantage of autonomous water taxi
Limited number of depot or terminal	Multiple parking spots
Restricted depot location	Parking spot in the middel of the water
Taxi allocation restriction	Free to adjust allocation

Increased Operational Flexibility

Water taxi in Bergen

- Develop a MIP for the facility location, fleet allocation and routing problem with water taxi
- Incorporate with all the pros and cons of manned and unmanned water taxi
- Run numerical test

Conclusion

- The existing literature on autonomous vessels is collected, summarized and categorized.
- The popularity of autonomous vessels in research has increased significantly in recent years
- Top countries/regions and journals with most publication on autonomous vessels are identified
- The research on autonomous vessels is well developed in the areas of safety and navigation control. However, comparing with a similar subject - autonomous vehicles - the study of autonomous vessels in transportation and logistics is very weak.
- Great potentials can be expected from the category of transporation and logistics and the researchers should put more efforts on this field.

NHH

CENTRE FOR SHIPPING AND LOGISTICS