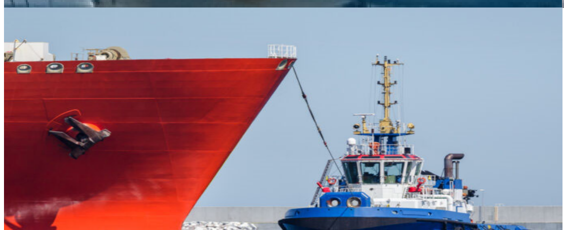

Smart Shipping & Logistics: Perspectives & Challenges

"anticipating the massive introduction of
sensing, actuation, computation, and communication technology"

Prof.dr. Rudy Negenborn *et al.*

R.R.Negenborn@tudelft.nl

Researchlab Autonomous Shipping
Department of Maritime and Transport Technology
Delft University of Technology

Interreg 2 Seas Mers Zeeën

NWO

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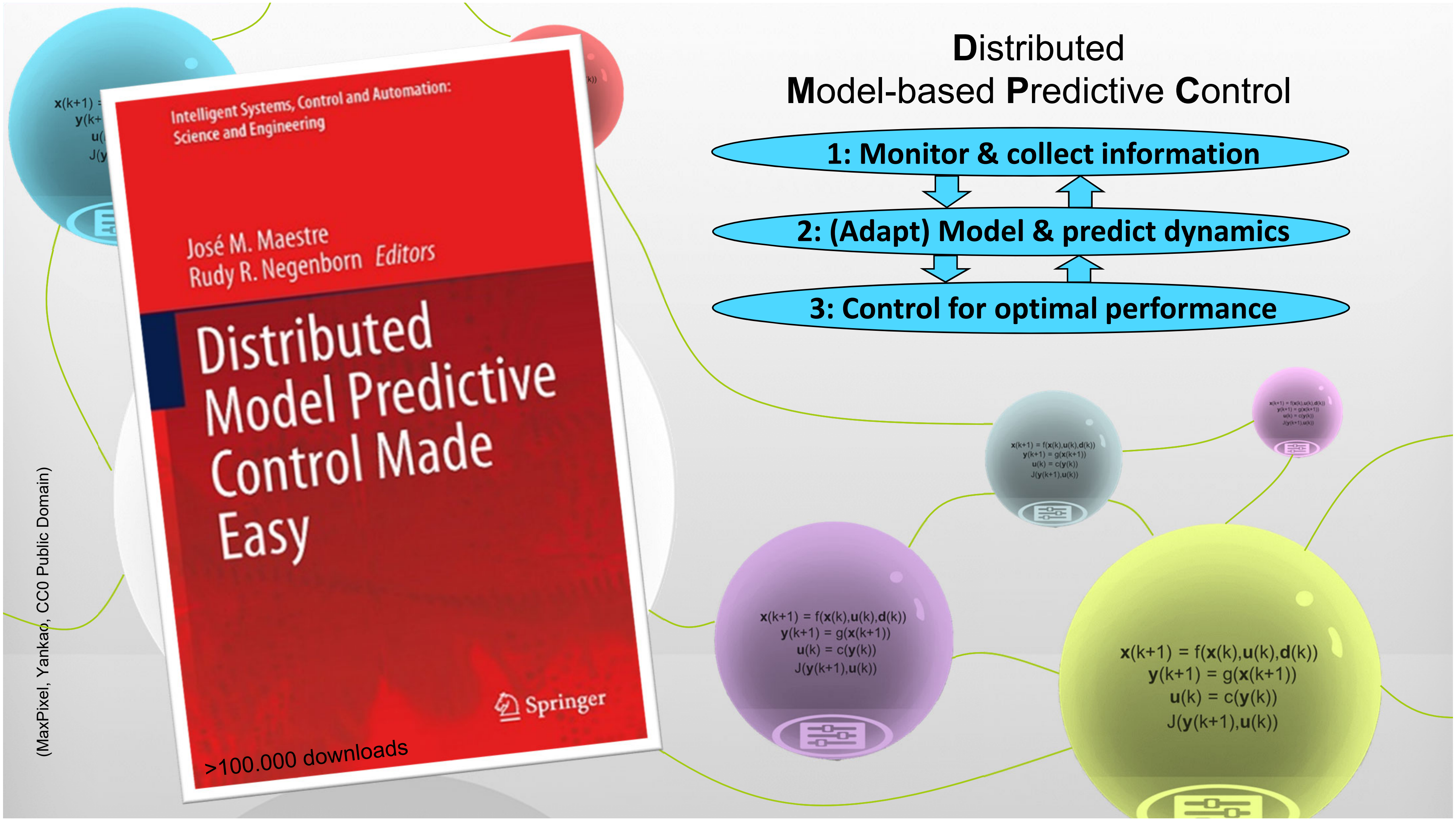
Distributed
Model-based Predictive Control
1: Monitor & collect information
2: (Adapt) Model & predict dynamics
3: Control for optimal performance
Intelligent Systems, Control and Automation: Science and Engineering
José M. Maestre
Rudy R. Negenborn Editors
Distributed Model Predictive Control Made Easy
Springer
>100.000 downloads
x(k+1) = f(x(k),u(k),d(k))
y(k+1) = g(x(k+1))
u(k) = c(y(k))
J(y(k+1),u(k))
(MaxPixel, Yankao, CC0 Public Domain)

Port automation for inspiration

(ECT, APMT, Rotterdam)

Mixed-purpose vehicles can deal with people and freight demand interchangeably.

92%	12%	18%	22%
Best results	Higher profits	More used vehicles	Lower occupancy

Integrating people and freight transportation using shared autonomous vehicles with compartments, Beirigo, Schulte, IFAC CTS, 2018

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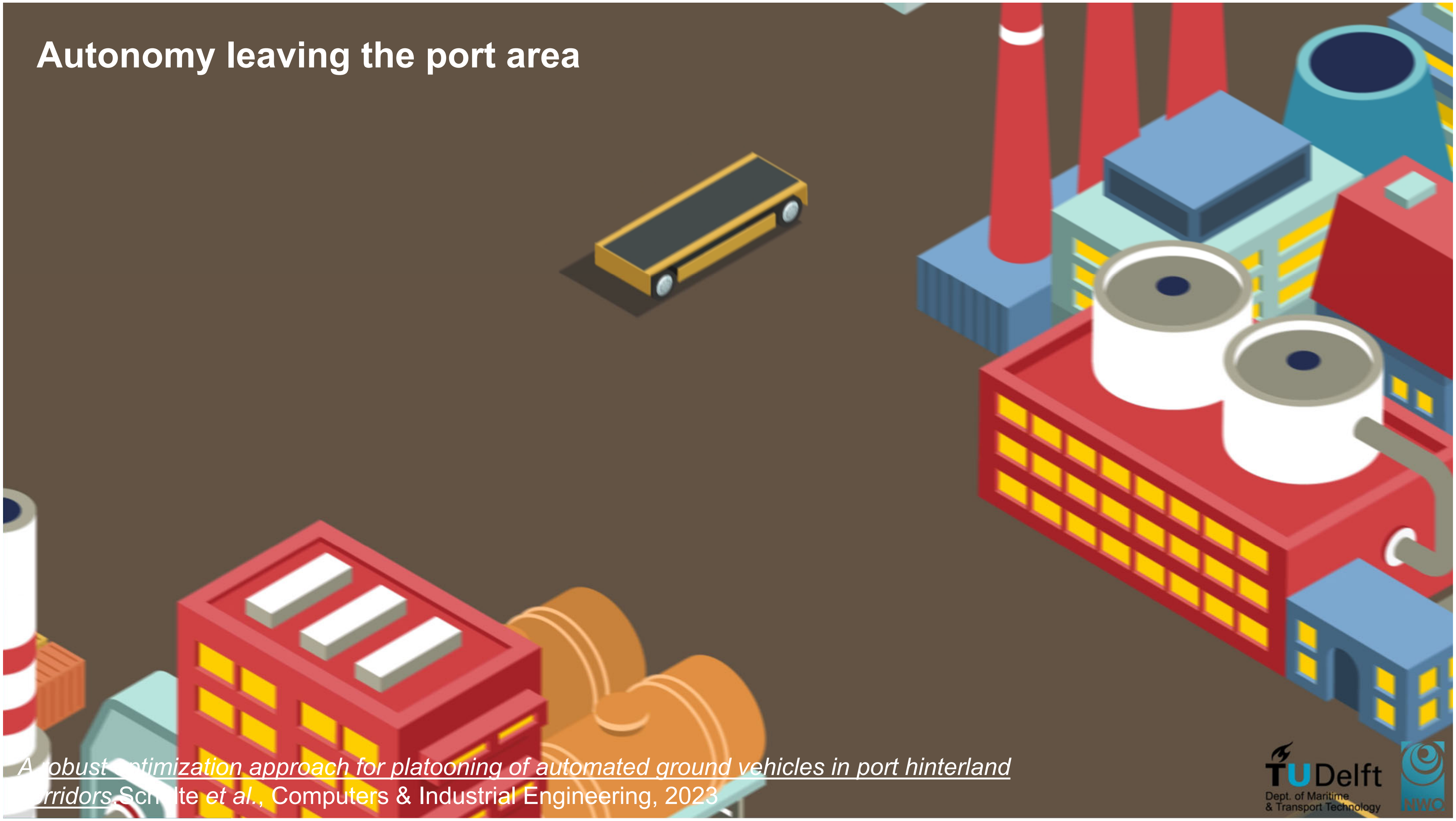
Autonomy leaving the port area



A robust optimization approach for platooning of automated ground vehicles in port hinterland corridors, Schulte *et al.*, Computers & Industrial Engineering, 2023

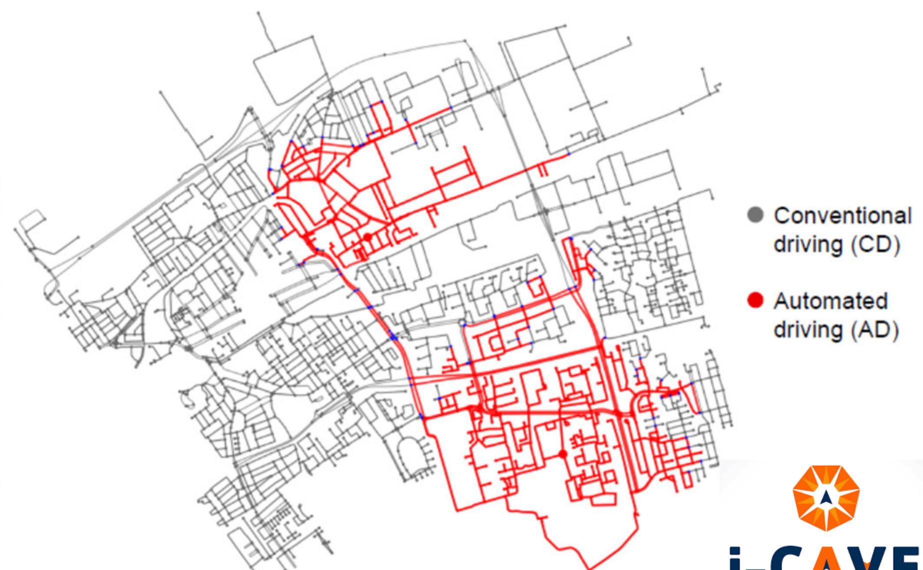
TU Delft
Dept. of Maritime & Transport Technology

Will AVs really run everywhere?

Dual-mode vehicle routing in mixed autonomous and non-autonomous zone networks

Our world today

Near to distant future



Dual-mode vehicle routing in mixed autonomous and non-autonomous zone networks, Beirigo, Schulte, IEEE ITSC, 2018

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- *Adaptive* control, coordination & health monitoring
- *Human-machine intelligence* interaction
- *Real-time* optimization of transport and logistics (e.g. construction materials, mobility solutions)
- *Experimental validation* using high-fidelity simulations with real-life data and actual vessels (fleet of ~20 vessels)


The Green Village

EUROPESE UNIE
Europees Fonds voor Regionale Ontwikkeling
Mede gefinancierd in het kader van de respons van de Unie op de COVID-19-pandemie.

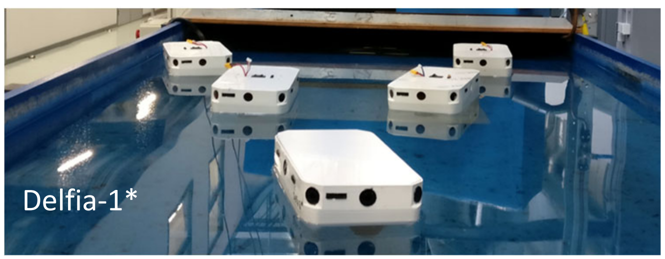
THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION
HORIZON 2020

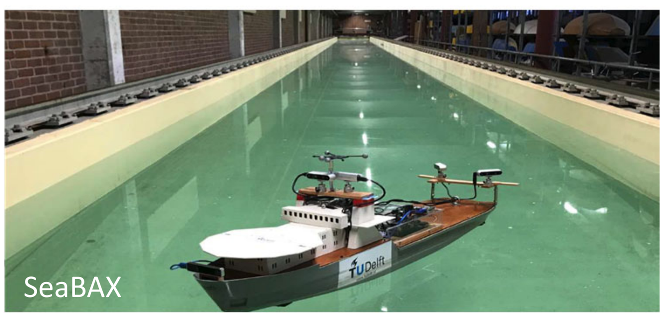
NWO

provincie Zuid-Holland

Interreg 2 Seas Mers Zeeën

Interreg North Sea Region
European Regional Development Fund
EUROPEAN UNION


Delfia-1*


SeaBAX


Vera Cruz


GeoXYZ

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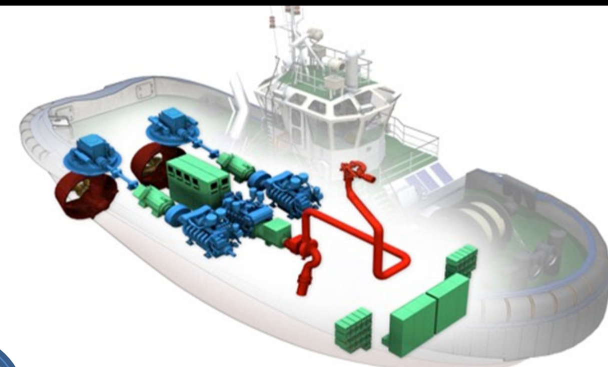
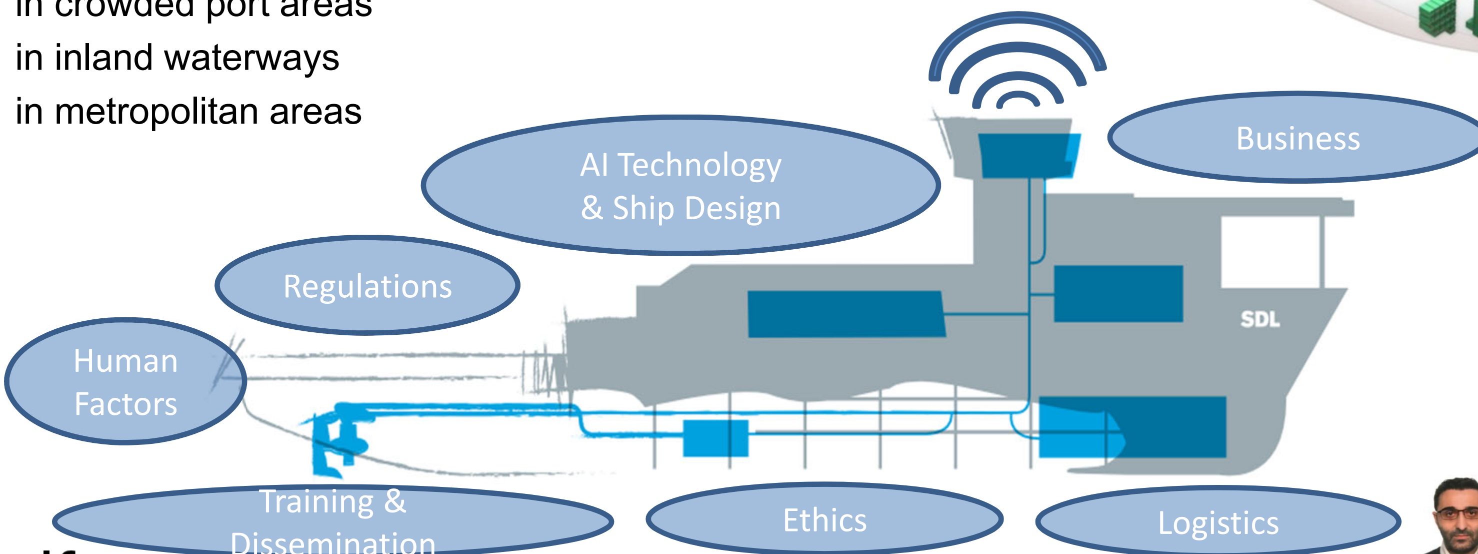
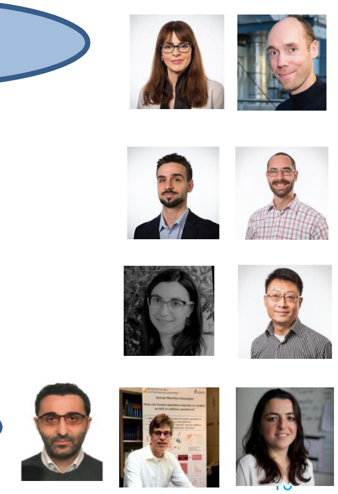
Multi-disciplinary approaches enabling green and autonomous transport

- on the open oceans
- in crowded port areas
- in inland waterways
- in metropolitan areas



Courtesy Damen





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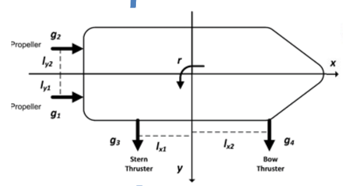
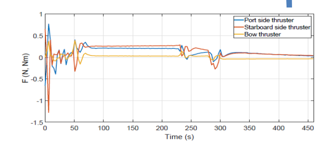
Single Autonomous Vessel

- Sustainability <-> Efficiency <-> Risk avoidance
- Machine Vision & Situational awareness
- Adaptive Predictive Manoeuvring Control
- Predictive Thrust Allocation & Energy Management

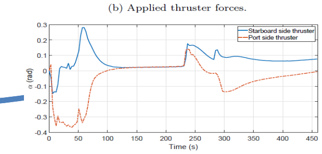


$$\mathbf{x}(k+1) = f(\mathbf{x}(k),\mathbf{u}(k),\mathbf{d}(k))$$
$$\mathbf{y}(k+1) = g(\mathbf{x}(k+1))$$
$$\mathbf{u}(k) = c(\mathbf{y}(k))$$

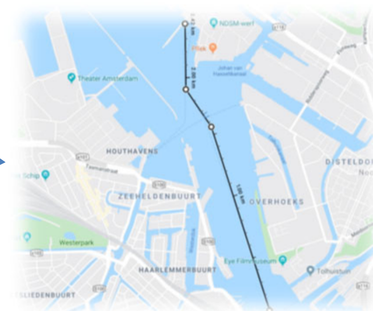
$$\max J(\mathbf{y}(k+1),\mathbf{u}(k))$$

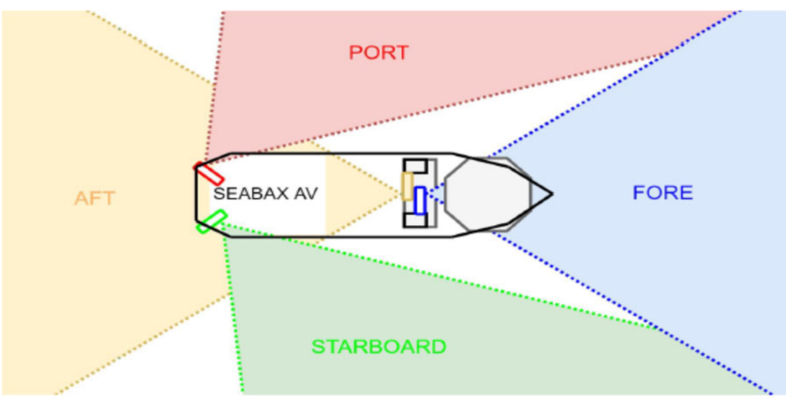


(b) Applied thruster forces.



(c) The angle of thrusters.





In collaboration with AMS & MIT Roboat

TU Delft

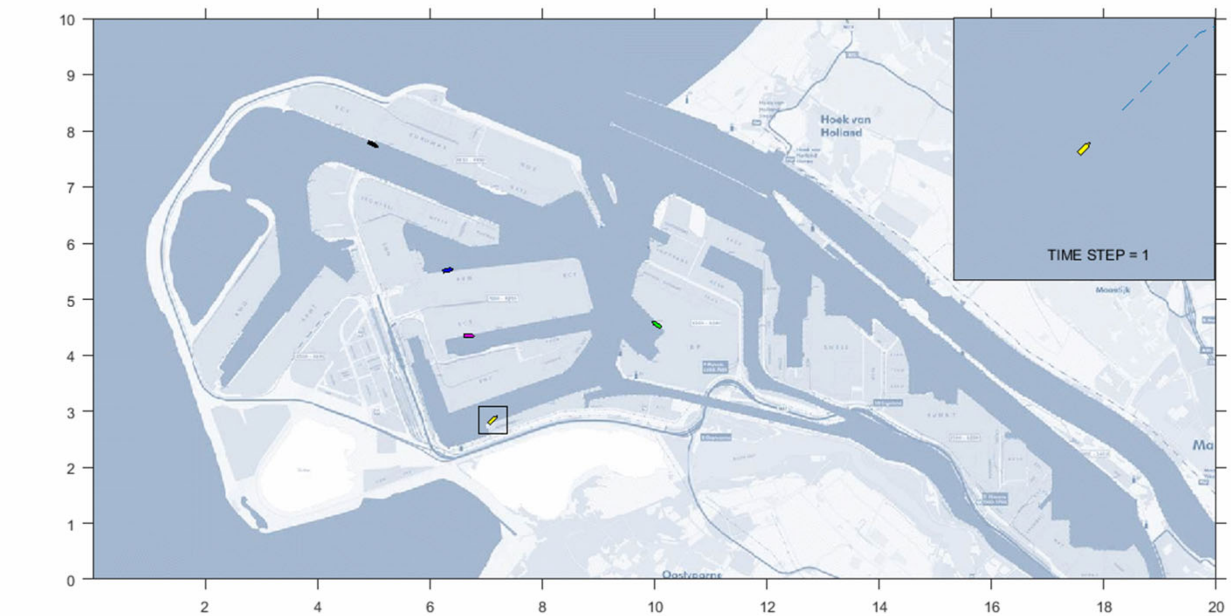
M. Hepworth, 2020; A. Haseltalab, V. Garofano et al., "Model Predictive Trajectory Tracking Control and Thrust Allocation for Autonomous Vessels," IFAC world congress 2020.

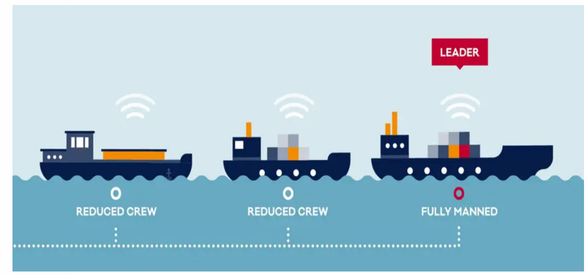
FAST FIELD LAB AUTONOMOUS SAILING TECHNOLOGY

OPZuid Europees Innovatieprogramma Zuid-Nederland

RESEARCHLAB AUTONOMOUS SHIPPING

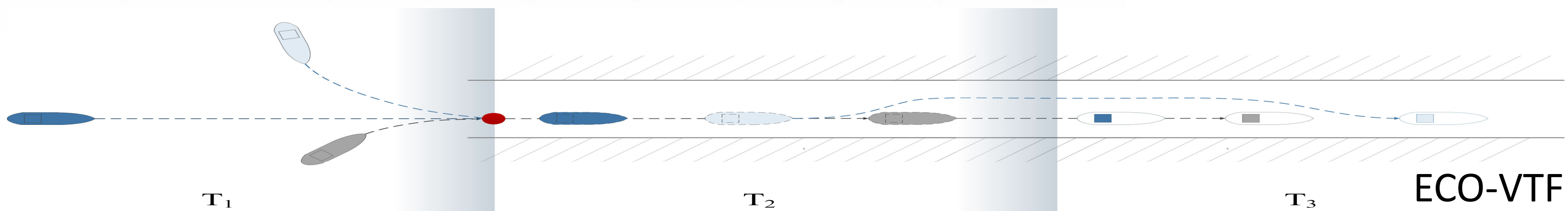
Fuel-Efficient Vessel Train Formations





NOVIMAR VESSELTRAIN

Horizon2020
European Union Funding
for Research & Innovation



ECO-VTF

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Distributed model predictive control for vessel train formations of cooperative multi-vessel systems, Transportation Research Part C: Emerging Technologies, vol. 92, pp. 101-118, July 2018.

Closed-loop scheduling and control of waterborne AGVs, Transportation Research Part E: Logistics and Transportation Review, vol. 105, pp. 261-278, 2017

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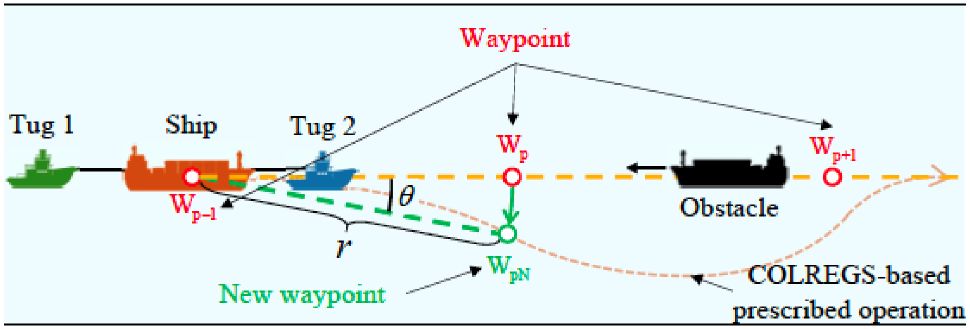
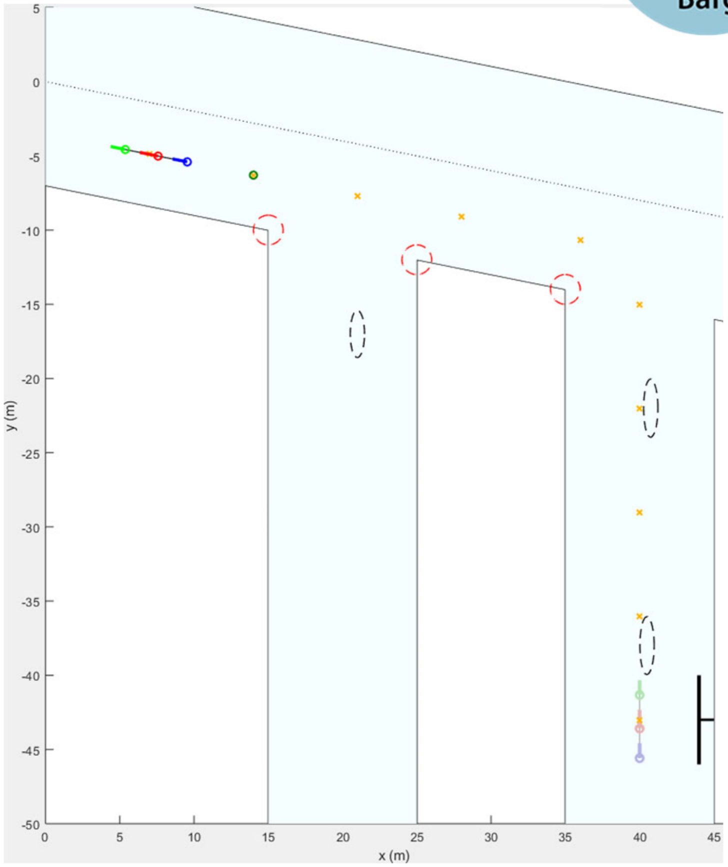
European Union Funding
for Research & Innovation

Object manipulation: Multi-Tug Ship Towing





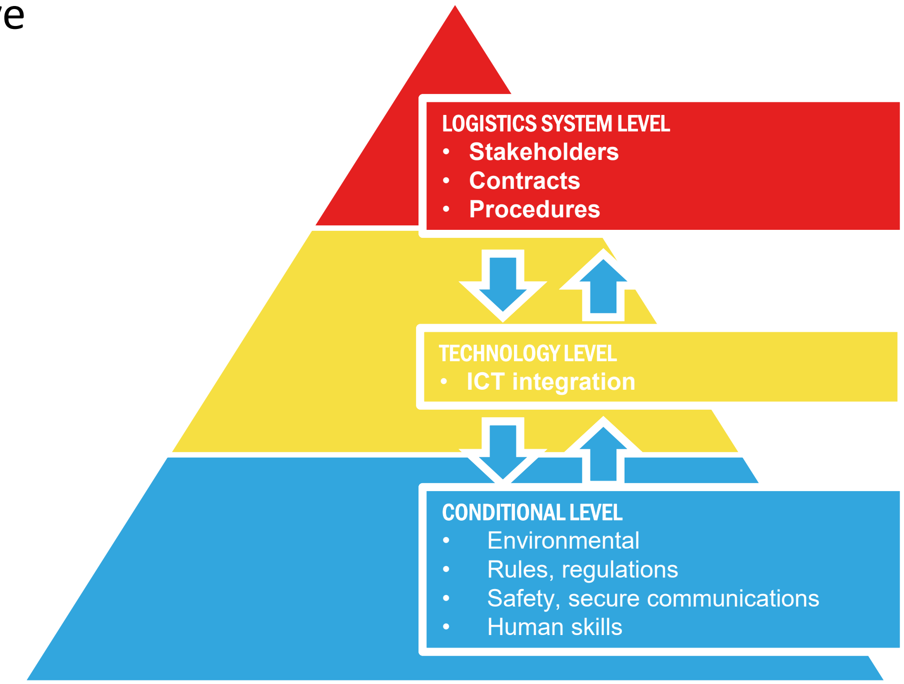
Cooperative multi-agent control for autonomous ship towing under environmental disturbances, Du, Reppa, *IEEE/CAA Journal of Automatica Sinica*, 2021.

Smart Logistics: Putting things in perspective

novimove

Smart & sustainable waterways

Make better use
of the capacity of
inland fleet and infrastructure,
and increase IWT
reliability and competitiveness



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Funded by the Horizon H2020 Programme of the European Union under grant agreement No 858508

Further reading on Autonomous Shipping

Defining autonomy levels: Survey on autonomous surface vessels: Part I – A new detailed definition of autonomy levels
In Proceedings of the 8th International Conference on Computational Logistics (ICCL 2017), Southampton, UK, pp. 219-233, October 2017.

Prototypes and applications: Survey on autonomous surface vessels: Part II – Categorization of 60 prototypes and future applications
In Proceedings of the 8th International Conference on Computational Logistics (ICCL 2017), Southampton, UK, pp. 234-252, October 2017.

Maritime ecosystem: Smart ships and the changing maritime ecosystem
SmartPort White Paper, 30 pp., September 2018.

Cooperative control: Survey on cooperative control for waterborne transport
IEEE Intelligent Transportation Systems Magazine, vol. 13, no. 2, pp. 71-90, 2020.

Collision avoidance: Ship collision avoidance methods: State-of-the-art
Safety Science, vol. 121 (2020), pp. 451-473, 2019.

Further reading on Autonomous Shipping

Motion control: State-of-the-art research on motion control of maritime autonomous surface ships
Journal of Marine Science and Engineering, vol. 7, no. 12, December 2019. Open access.

Application, technology and infrastructure: Autonomous surface vessels in ports: Applications, technology and port infrastructures
In Proceedings of the 9th International Conference on Computational Logistics (ICCL 2018), Vietri sul Mare, Italy, pp. 85-105, October 2018.

Short-term technology developments: Survey on short-term technology developments and readiness levels for autonomous shipping
In Proceedings of the 9th International Conference on Computational Logistics (ICCL 2018), Vietri sul Mare, Italy, pp. 106-123, October 2018.

Collaborative shipping: The Collaborative Autonomous Shipping Experiment (CASE): Motivations, theory, infrastructure, and experimental challenges
In Proceedings of the 2020 International Ship Control Systems Symposium (iSCSS 2020), Delft, The Netherlands, October 2020.

Smart Shipping: Perspectives & Challenges

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V. Reppa, B. Atasoy, V. Garofano, Y. Pang,
A. Coraddu, F. Schulte, *et al.*

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