SpatioTemporal AI for Maritime Digitalisation and Decarbonisation

Tao Cheng + Team

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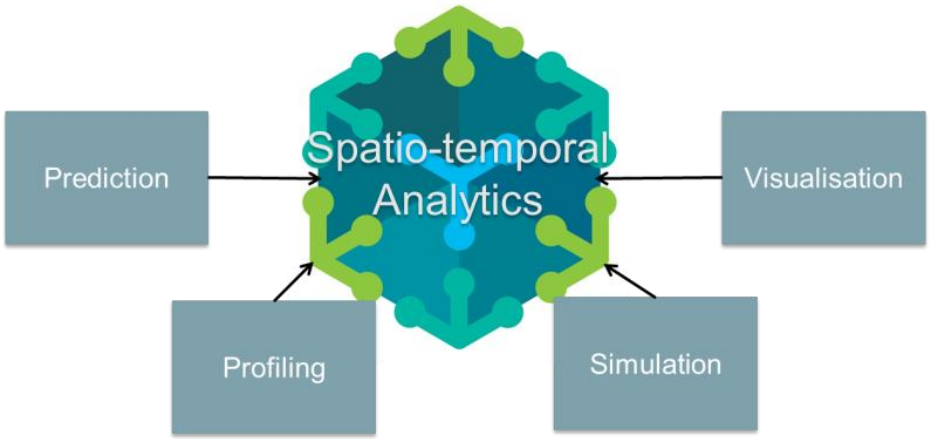
Theme Lead in Mobility, The Alan Turing Institute

Our Vision is to generate actionable insights & foresight from geo-located and time-stamped data for government, business and society.

Using integrated spatiotemporal thinking, a network-based approach, and cutting-edge AI, we engineer solutions to improve mobility, safety, health and prosperity of urban living.



Elements of spatio-temporal Big Data analytics

Transport & Mobility

Crime & Safety

Business Intelligence

Environment & Resilience

STANDARD
Spatio-Temporal Analysis of Network Data And Road Developments

CrimePolicingCitizenship
space-time interactions of dynamic networks

Consumer Data Research Centre

INFRARISK

TRANSPORT FOR LONDON
EVERY JOURNEY MATTERS

METROPOLITAN POLICE

British Gas

ARUP

ublox

LFB
LONDON FIRE BRIGADE

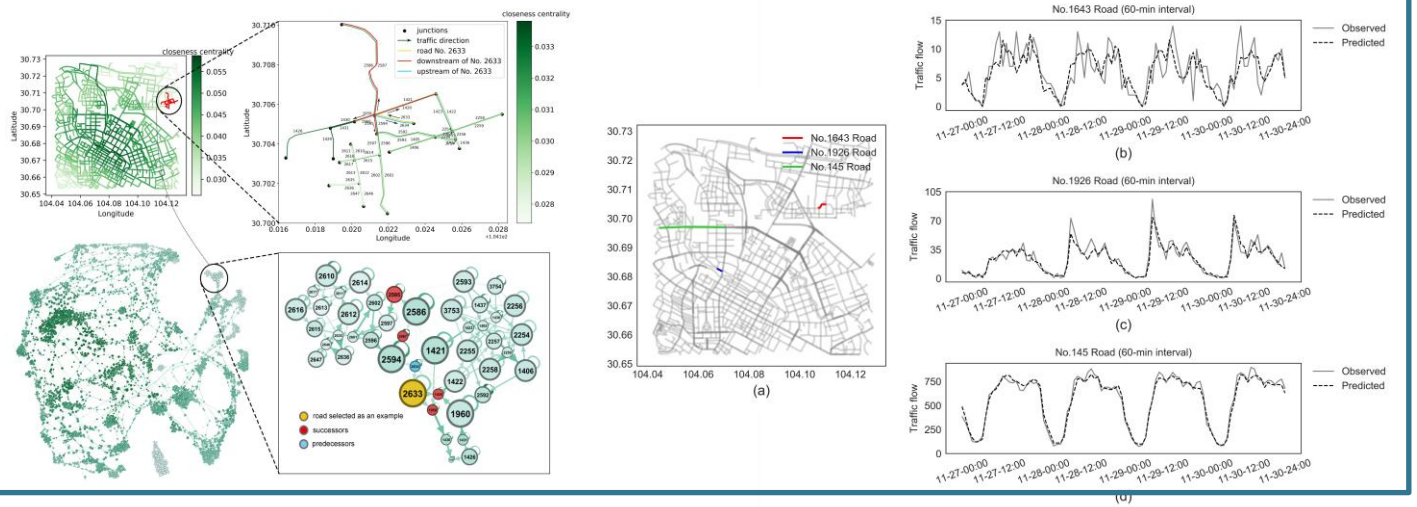
WORCESTER
Bosch Group

CATAPULT
Connected Places

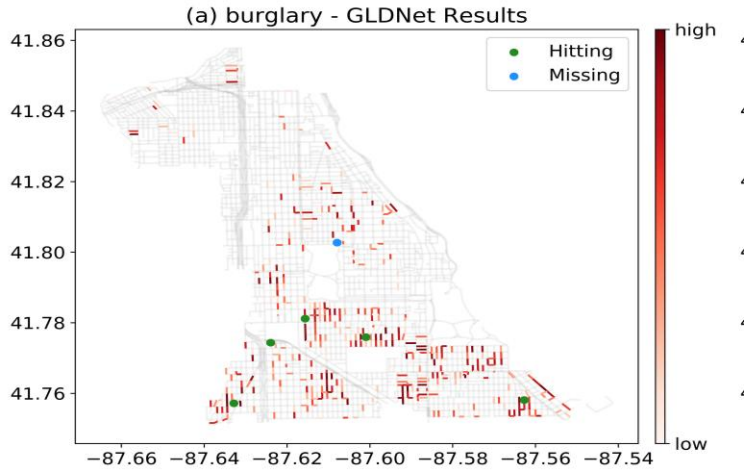
Research Development

➢ *2016-2022 : SpaceTimeAI* - Utilising Graph & deep learning to model space-time processes

1. Dense event prediction – Traffic flow prediction (Zhang et al, 2019)

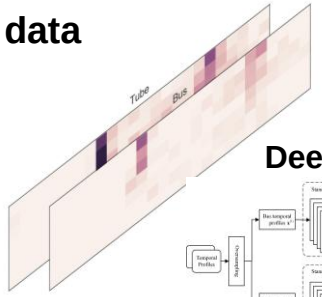


2. Sparse event prediction – Crime (Zhang & Cheng, 2020)



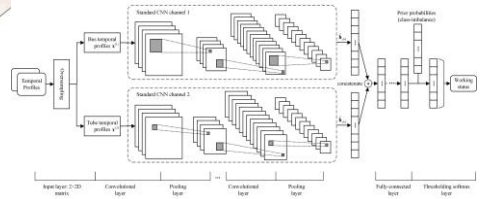
3. Geodemographic & Employment status inference (Zhang, et al., 2020)

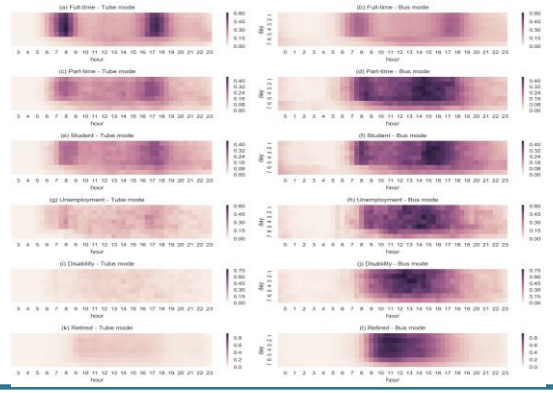
Smart card data



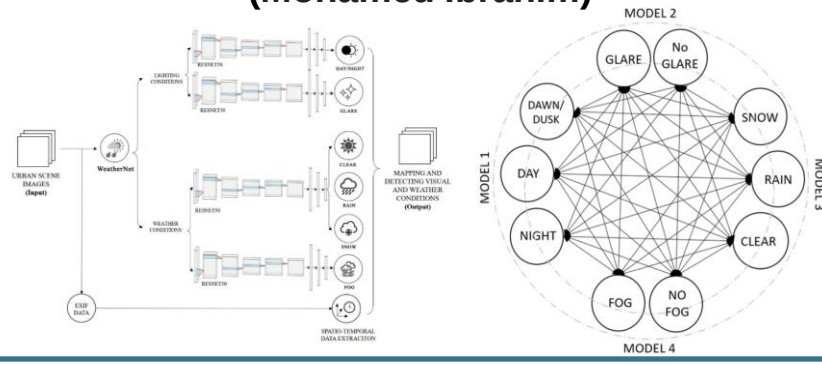
Travel behaviour representation

Deep learning model





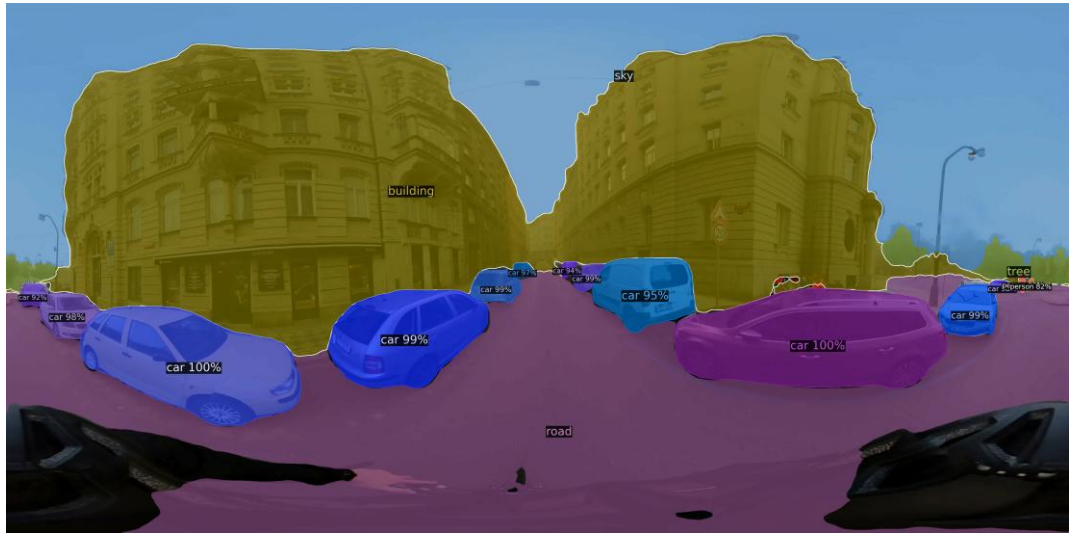
4. Recognising weather and visual conditions (Mohamed Ibrahim)



Yang Zhang, Tao Cheng, and Yibin Ren, "A graph deep learning method for short-term traffic forecasting on large road networks," *Computer-Aided Civil and Infrastructure Engineering,* vol. 34, pp. 877–896, 2019.

Safety and Security – Understanding risk using computer vision

- Detecting people, objects, and environments
- Extracting risk factors
- Improving road safety



STAGE 1

Data Collection

- **Panoramic videos**
- **Location of accidents**

STAGE 2

Data Processing

- **Object detection**
- **Multi-object tracking**

STAGE 3

Risk Detection

- **Overtaking behaviour detection**
- **Near miss detection**

Guo et al. (2024) Multiple Object Detection and Tracking in Panoramic Videos for Cycling Safety Analysis, DOI: 10.48550/arXiv.2407.15199

2022 - Now : STGAI

- **Framework for motorcycle risk assessment**

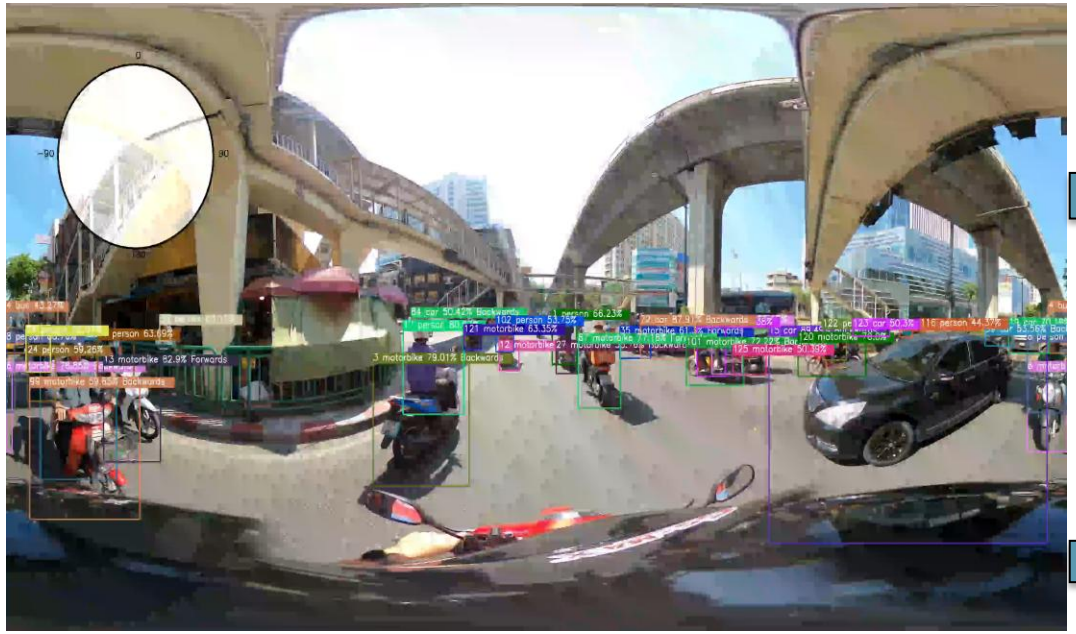
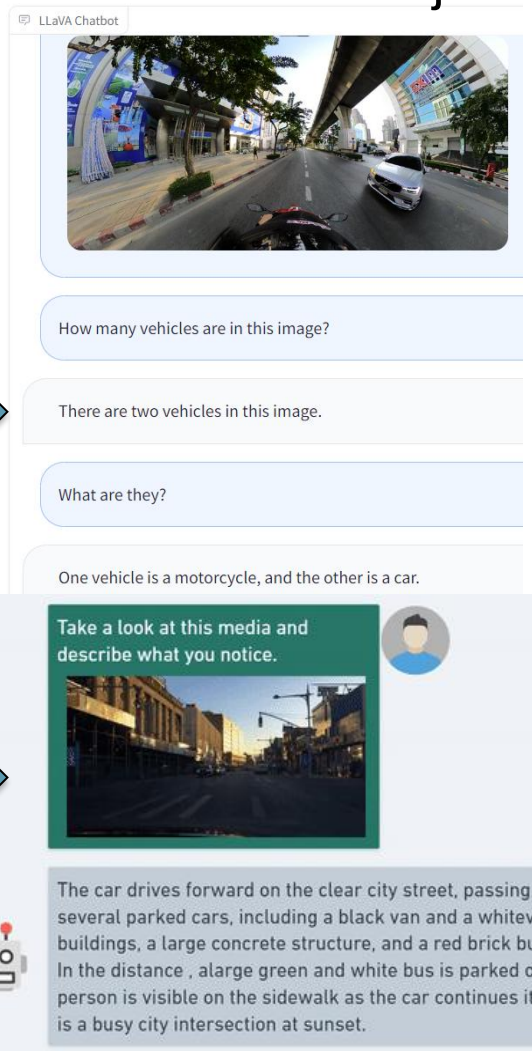


Image-to-text: Static objects/ Environments



Risks

Video captioning: Interactions/ Moving objects

Chula Chulalongkorn University

This work was funded by the Faculty of Engineering, Chulalongkorn University and UCL's Global Engagement Fund

2020 - 2025 : New form of data for sustainability

SpaceTimeAI - Unlocking the Power of Mobile Phone Data to Understand Travel Behaviour for Sustainability

Transport interventions

Low Traffic Neighbourhood Scheme

Travel mode detection

- Massive volume
- User dependent
- Relative sparse

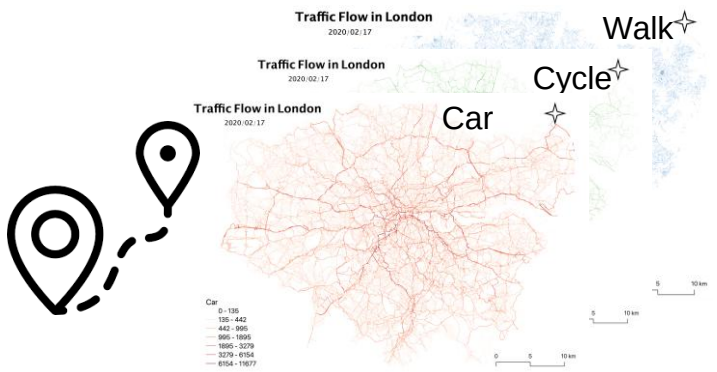
- Comprehensive travel modes
- Broad group identification
- High accuracy

Mobile phone data

New form of travel services

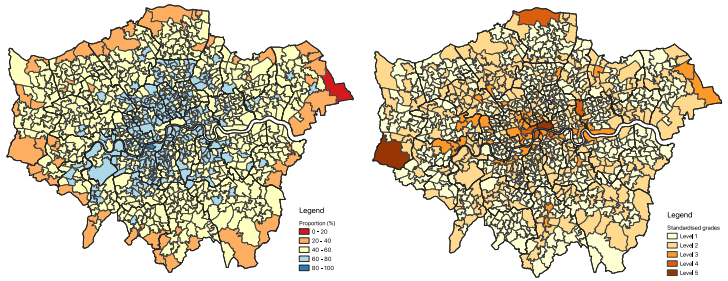
Share mobility

Monitoring multimodal mobility



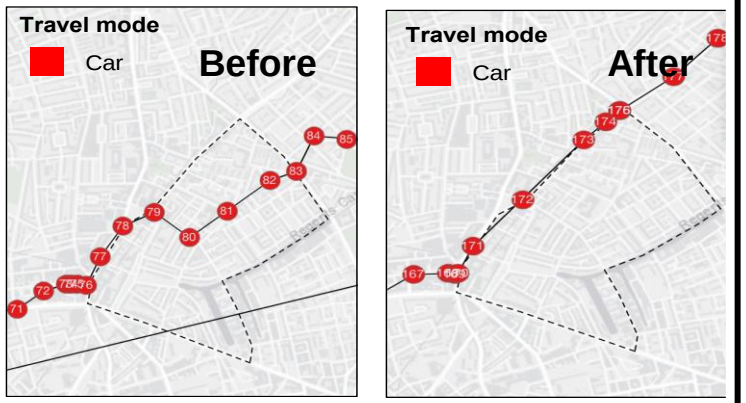
Individual level **Network level**

Understanding the progress of sustainable mobility targets



Active travel targets **Transport GHGs emissions**

Evaluating transport interventions



Low Traffic Neighbourhood scheme

SpaceTimeLab

Zhang, X., & Cheng, T. (2022). The impacts of the COVID-19 pandemic on multimodal human mobility in London: A perspective of decarbonizing transport. Geo-spatial Information Science. doi:10.1080/10095020.2022.2122876

UCL ENGINEERING
Change the world

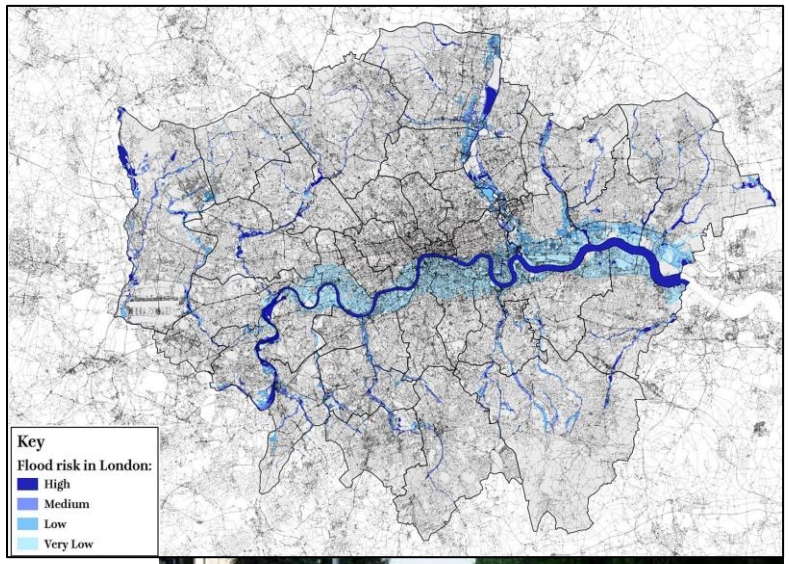
2022 - Now : Digital Twins – on going

IMproving flood-disruPted road networks resilience with dynAmic people-Centric digital Twins (IMPACT)

PI: Qiuchen Lu, Co-I Tao Cheng

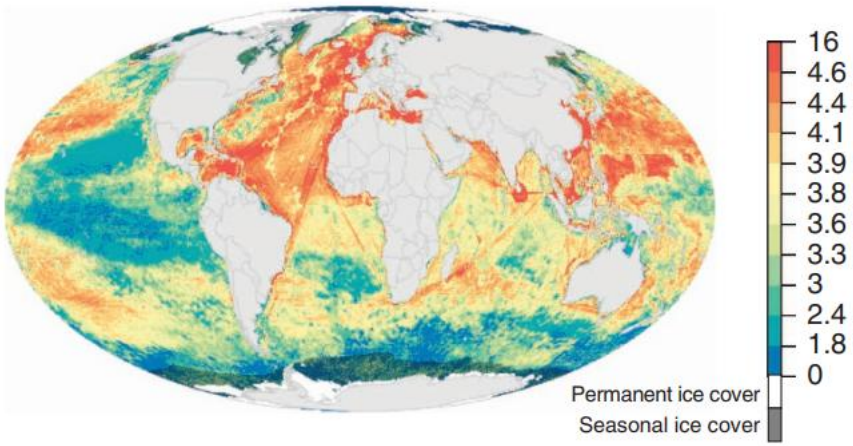
- In the UK, escalating flood increasingly affect people and property, intensifying pressure on national road networks.
- Approximately **6,600 kilometres** of UK roads are within regions prone to flooding, and this is anticipated to increase by up to 160% by the 2080s if adaptation measures are not implemented.
- The A303 has been closed for **days** after heavy rainfall-induced flooding since Storm Ciarán in November 2023.

The goal is to assess and improve the resilience of road networks in fast-changing flood through the multimodal people-centric digital twin.



SpaceTimeAI in Maritime

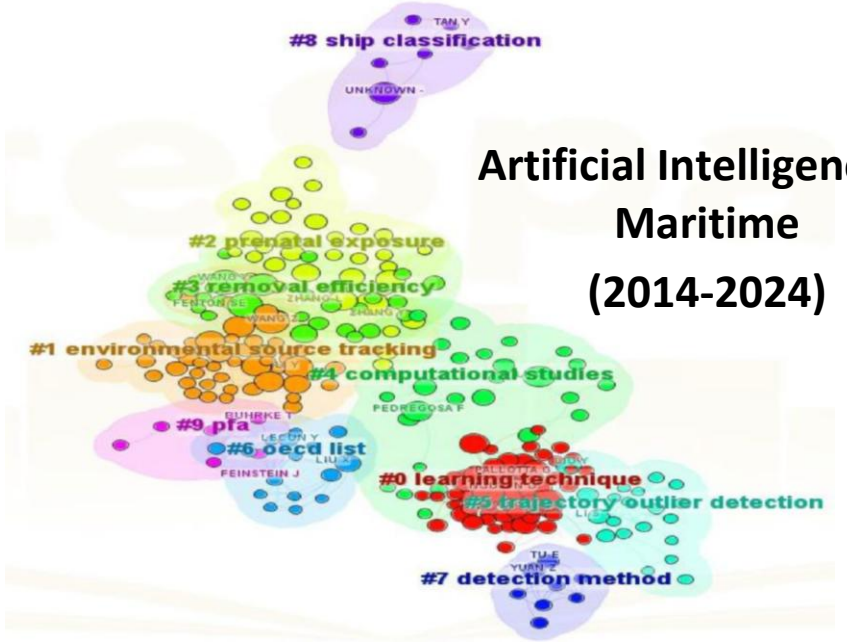
Cumulative human impact to marine ecosystems



As global human activities intensify, The cumulative impact on marine ecosystems is continuously increasing, particularly in coastal regions.

Halpern et al. (2015), "Spatial and temporal changes in cumulative human impacts on the world's oceans," Nature Communications, doi: 10.1038/ncomms8615.

Artificial Intelligence in Maritime (2014-2024)



- Sustainable maritime development.
- Interdisciplinary and AI-driven computational methods.
- Pollution tracking, fisheries management, vessel behavior analysis.

Thakur et al. (2025), "Artificial Intelligence in Maritime Anomaly Detection: A Decadal Bibliometric Analysis (2014–2024)," Journal of The Institution of Engineers (India): Series C, Jan. 2025, doi: 10.1007/s40032-025-01169-w.

Maritime Digitalisation & Decarbonisation

Social Responsibility

- Real-Time Monitoring & Emergency Response
- Data Integration and Multi-Source Fusion
- Global Environmental Policy Support

Economic Viability

- Smart Shipping and Fuel Optimisation
- Sustainable Blue Economy Growth
- Circular Economy for Marine Waste Reduction

Environmental Protection

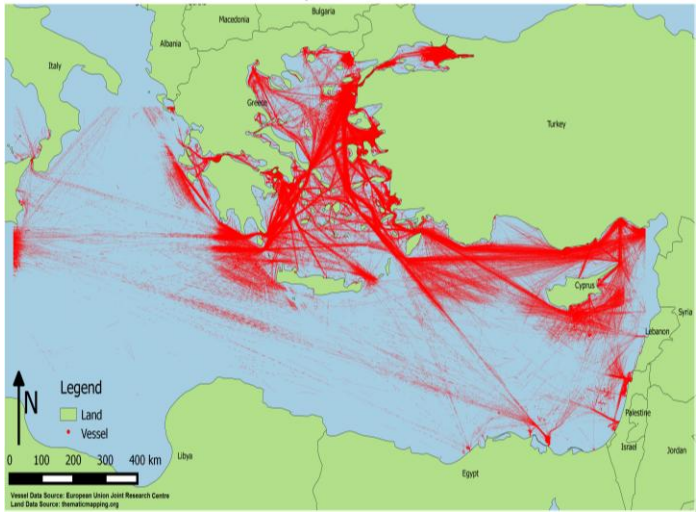
- Marine Ecosystem Protection
- Marine Biodiversity Monitoring
- Ecosystem Marine Governance
- Resilience to Climate Change

International Maritime Organization. (n.d.). IMO and Sustainable Development Goals (SDGs). IMO. Retrieved September 13, 2024, from https://wwwcdn.imo.org

Social Responsibility

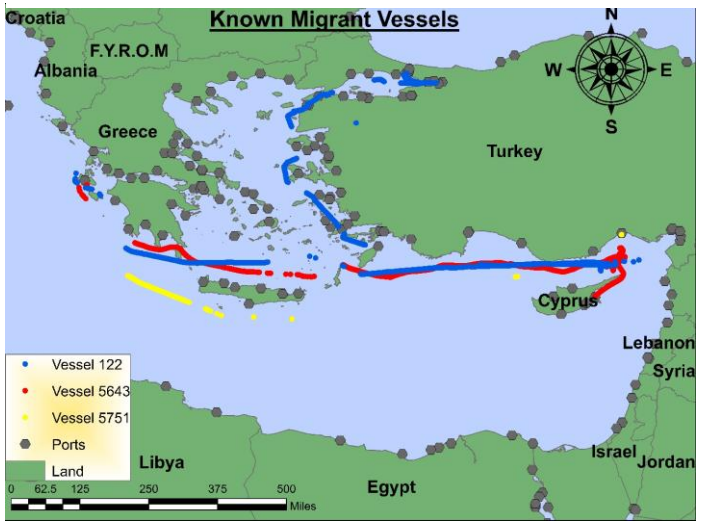
Vessel Monitoring and Analysis:
Identifying Potential Illegal Migrant Activity Amid Data Gaps

All Vessels, December 2014



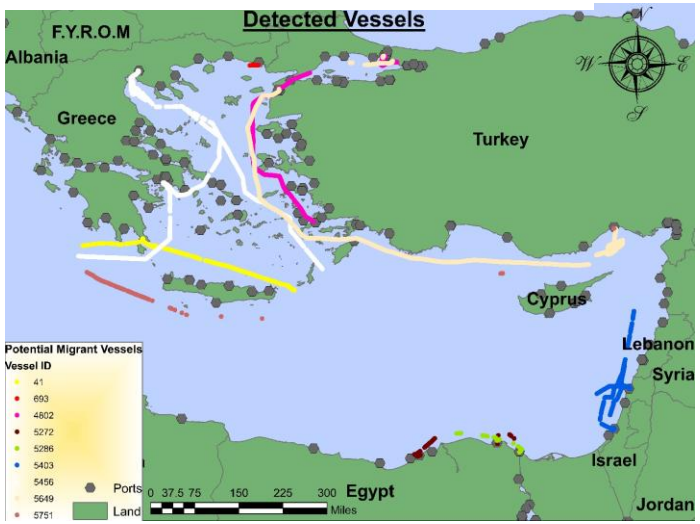
- 3000+ Vessels
- Data gaps are evident

Three known illegal boats



- Complicated behaviours

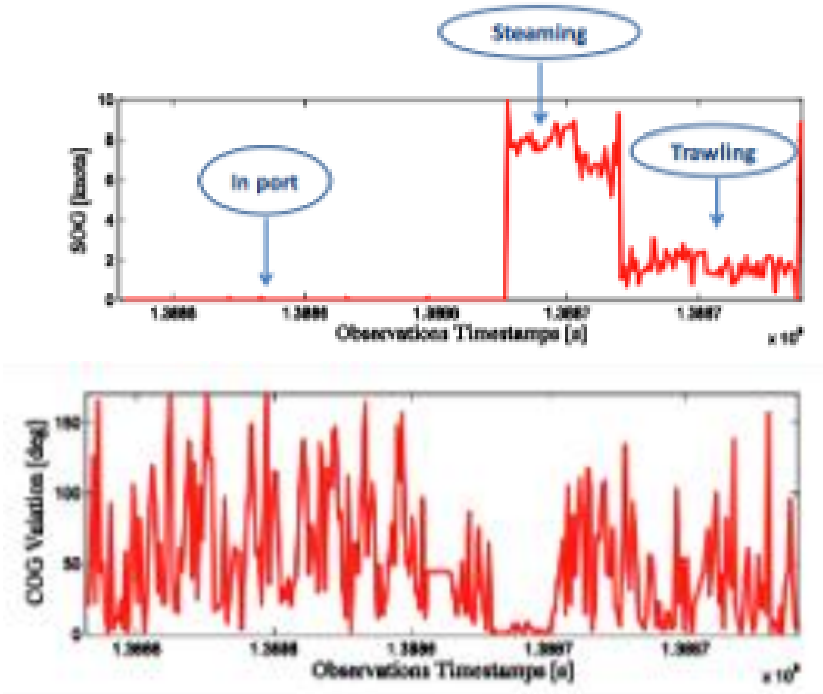
Detected vessels



- Nine Vessels Identified
  - One Fishing, Eight Cargo
  - Subject to further exploration

Illegal fishing - Data driven knowledge extraction from fishing vessel

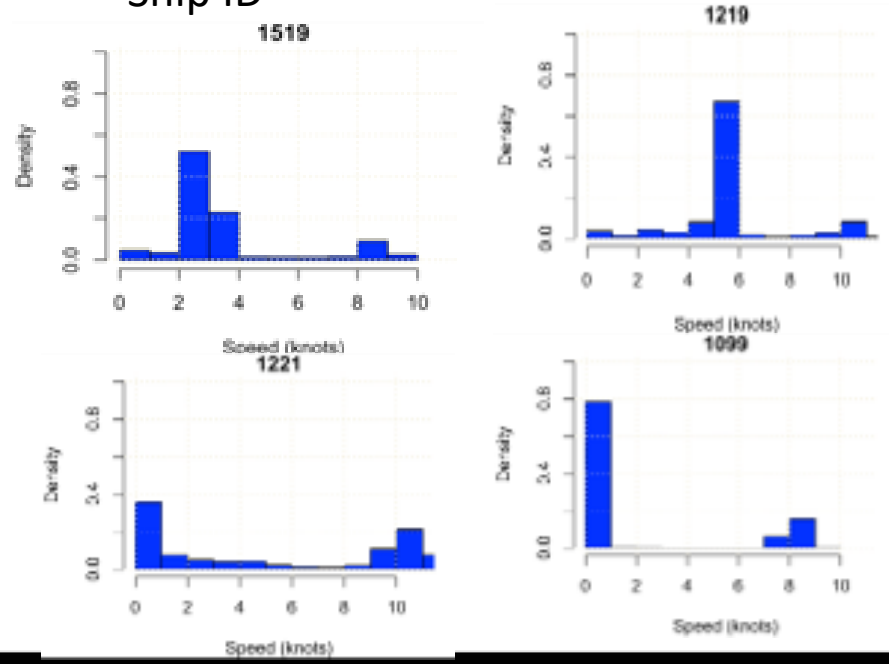
Overexploitation of fish stocks has led to worldwide losses of roughly $10-23 billions per year. Such levels of malpractices are severely threatening the marine ecosystems and the lives of the people who leave on coastal areas.



DATA & STUDY AREA

One month of historic fishing data (clean and anonymous) ~2.7M in the Adriatic Sea:

- Position (long, lat)
- Speed Over Ground (knots)
- Course Over Ground (degrees)
- Timestamp (5 min)
- Ship ID



SpaceTimeLab

MSc student : Betty (Despoina) Saridou

Supervisor: Prof Tao Cheng (UCL), Michele Vespe (JRC)

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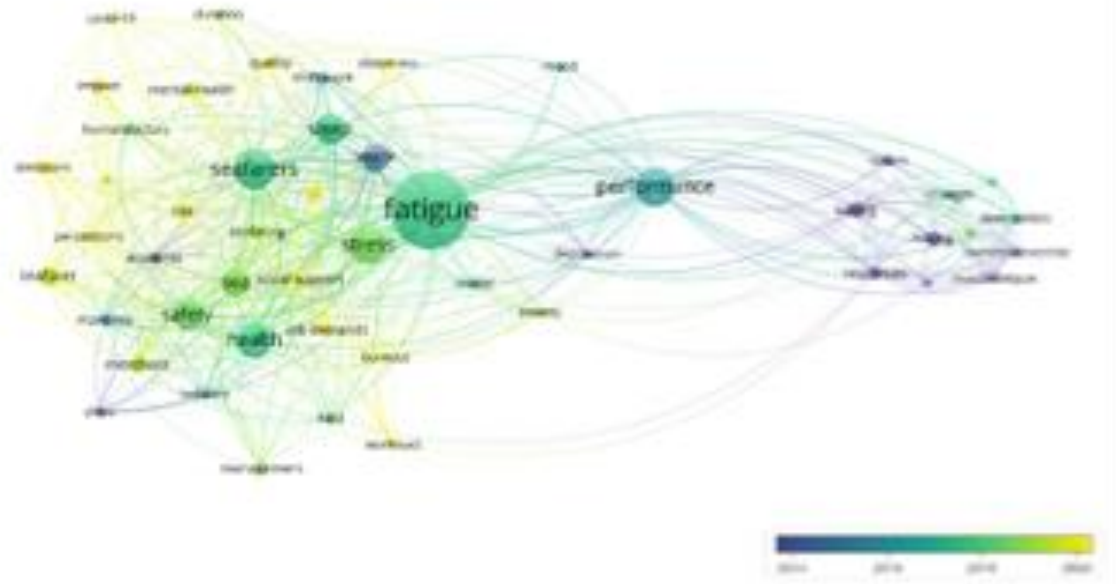
Social responsibility

Crew fatigue is the primary cause of maritime accidents.

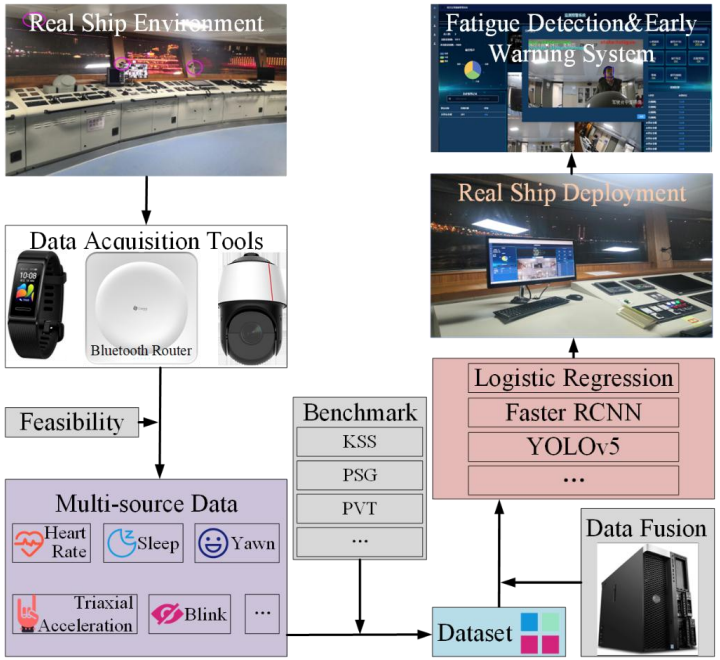


- **Global Importance:**
  90% of cargo is shipped, so maritime safety is critical.
- **Crew Fatigue Impact:**
  Fatigue in watch officers is a key cause of accidents.
- **Detection Challenges:**
  Fatigue detection on ships is harder due to automation and unique conditions.
- **Method Limitations:**
  Current methods are often subjective or non-real-time.
- **Need for Data Fusion:**
  Need for low-intrusive, real-time, multisource data approaches.

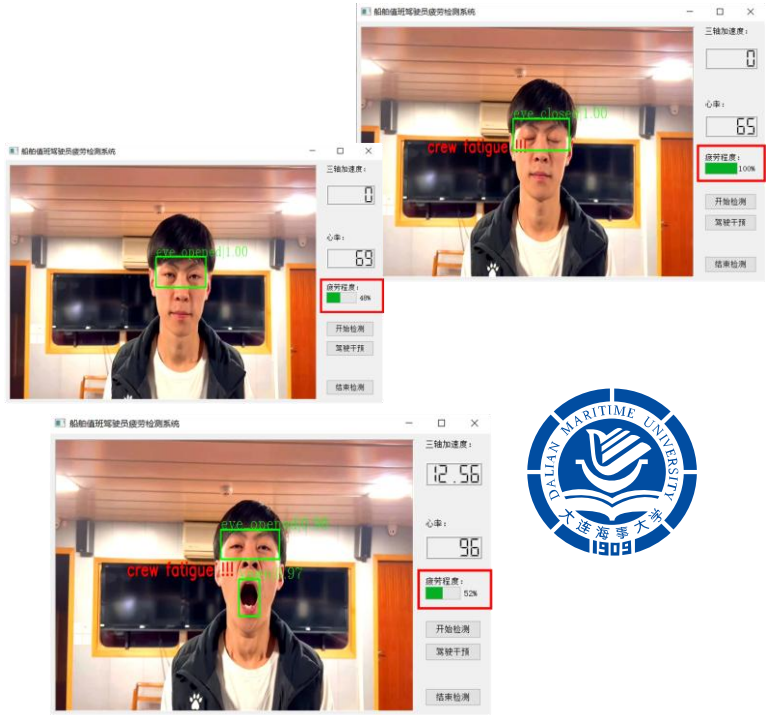
Reference: H. Lyu, J. Yue, W. Zhang, T. Cheng, Y. Yin, X. Yang, X. Gao, Z. Hao, and J. Li, "Fatigue Detection for Ship OOWs Based on Input Data Features, From the Perspective of Comparison With Vehicle Drivers: A Review," IEEE Sensors Journal, vol. 23, no. 14, pp. 15239–15250, July 2023, doi: 10.1109/JSEN.2023.3281068.

Social responsibility

➢ Fatigue Detection for Ship OOWs



➢ **Hybrid approach – armband + eye + mouth**



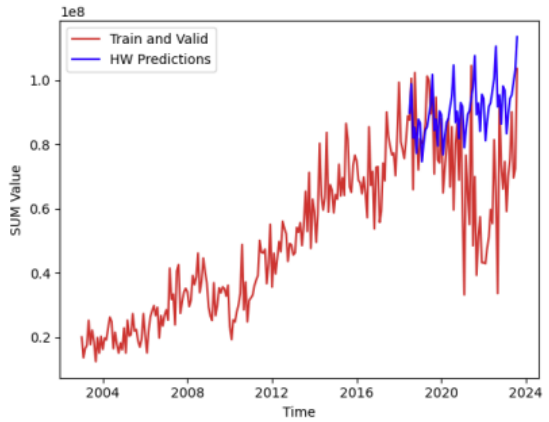
- Preprocess multi-source data, extract spatiotemporal features, and fuse video with wearable data for real-time, accurate ship officer fatigue monitoring.
- Promote non-invasive detection technology to provide cutting-edge AI support for sustainable maritime operations and smart shipping.
- Leverage vehicle fatigue detection methods by analogy and apply them to seafarer fatigue detection.

H. Lyu, J. Yue, W. Zhang, T. Cheng, Y. Yin, X. Yang, X. Gao, Z. Hao, and J. Li, "Fatigue Detection for Ship OOWs Based on Input Data Features, From the Perspective of Comparison With Vehicle Drivers: A Review," IEEE Sensors Journal, vol. 23, no. 14, pp. 15239–15250, July 2023, doi: 10.1109/JSEN.2023.3281068.

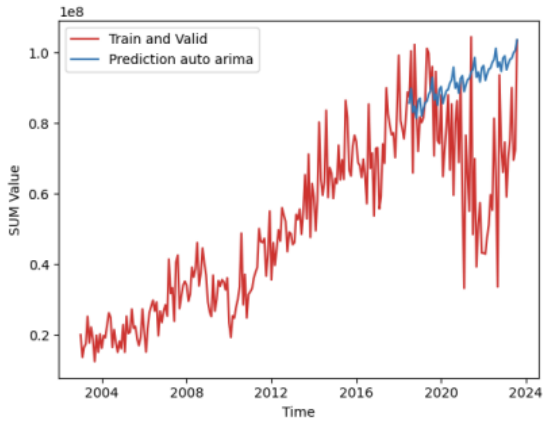
Economic Viability

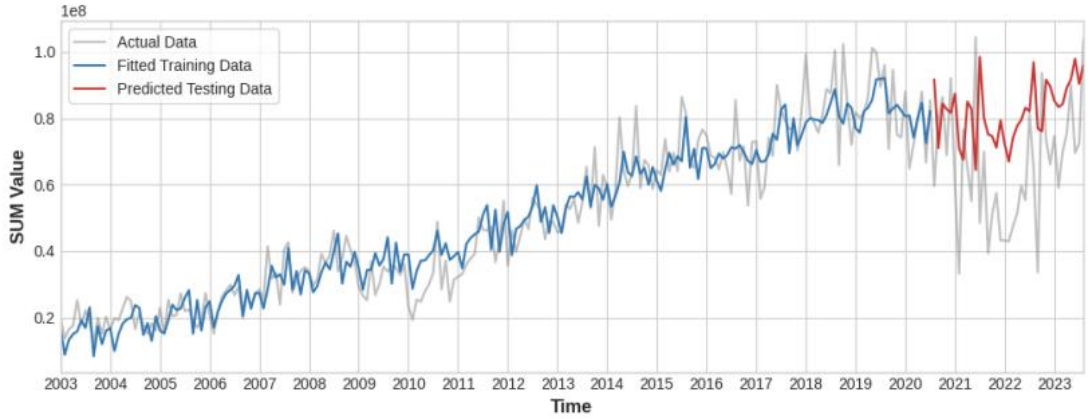
➢US Import Supply Chain Dynamics (Aristov & Li 2024)

(a) *Holt-Winters Model Result*



(b) *Auto ARIMA Model Result*





- ➢ Identified congestion points along U.S. ports using AIS data and DBSCAN.
- ➢ Predicted containerised goods' value and weight with high accuracy using GNN.

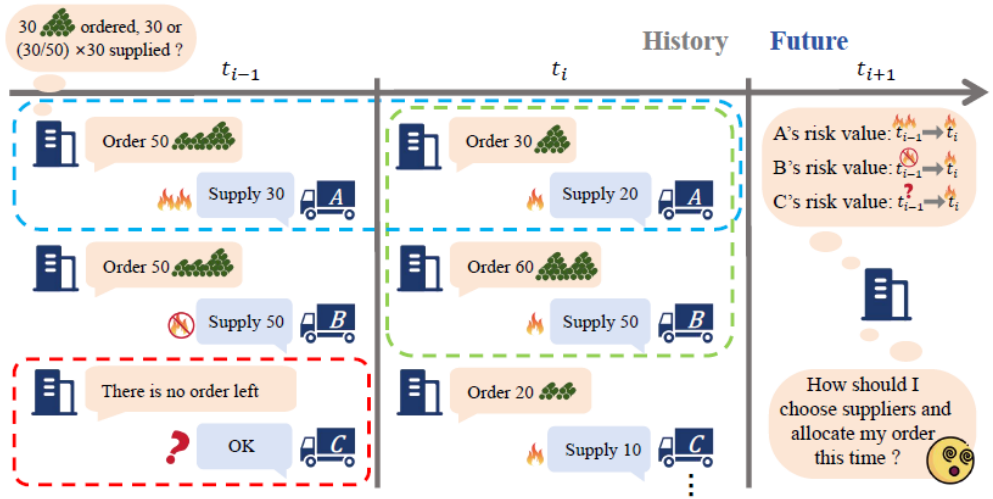
- Enhance **supply chain efficiency**
- Improve resource allocation and reduce delays to optimise economic outcomes.

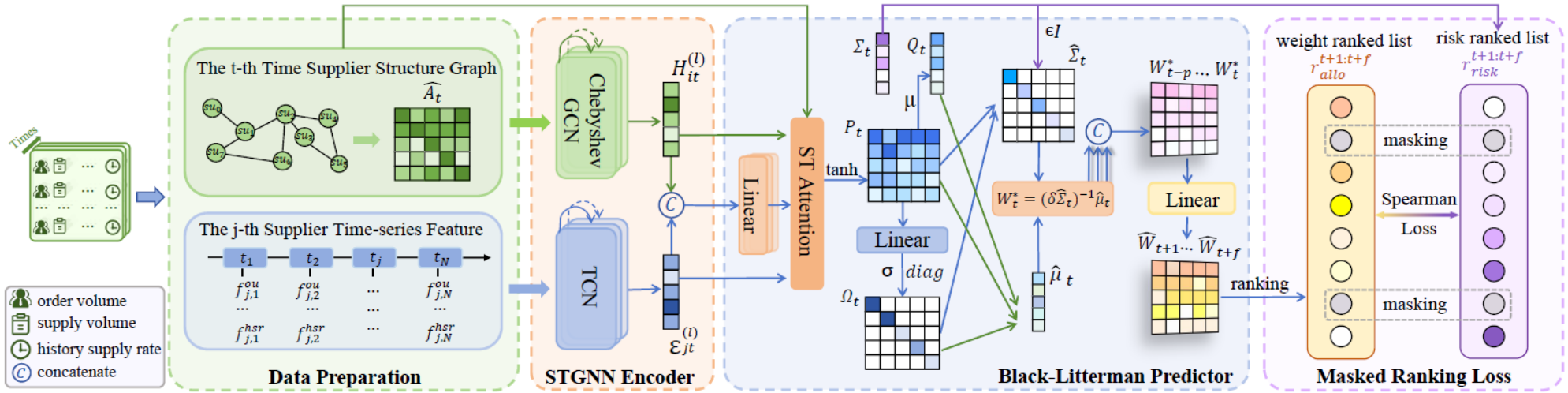
Aristov, N., & Li, Z. (2024). Elucidating US import supply chain dynamics: A spatial-temporal graph neural network approach [Master's thesis, Massachusetts Institute of Technology]. MIT Center for Transportation & Logistics.

Economic Viability

➢Time Series Supplier Allocation (Luo et al., 2024)

- **Feature Extraction:**
  Time series data from orders and supplies are extracted.
- **Spatio-Temporal Modeling:**
  GCN and TCN are used to capture supplier dynamics.
- **Enhanced Allocation Framework:**
  Black-Litterman model with masked ranking loss integrates.
- **Application:**
  Suitable for optimising supply chain allocation for ports

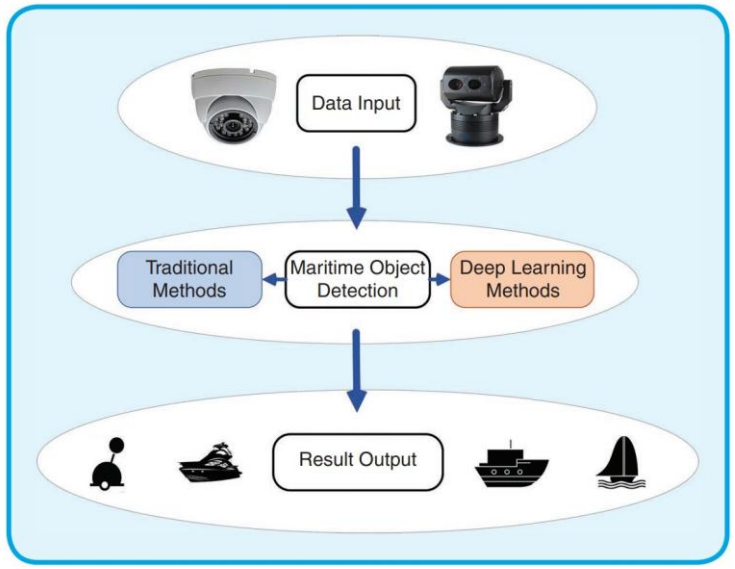




Reference: J. Luo, W. Zhang, Y. Fang, **X. Gao**, D. Zhuang, H. Chen, and X. Jiang, "Time Series Supplier Allocation via Deep Black-Litterman Model," in Proc. KDD '24, Barcelona, Spain, Aug. 25–29, 2024. https://arxiv.org/abs/2401.17350

Environmental Protection

➢ Detect and monitor sea-surface threats (e.g., oil spills) using EO sensors and AI



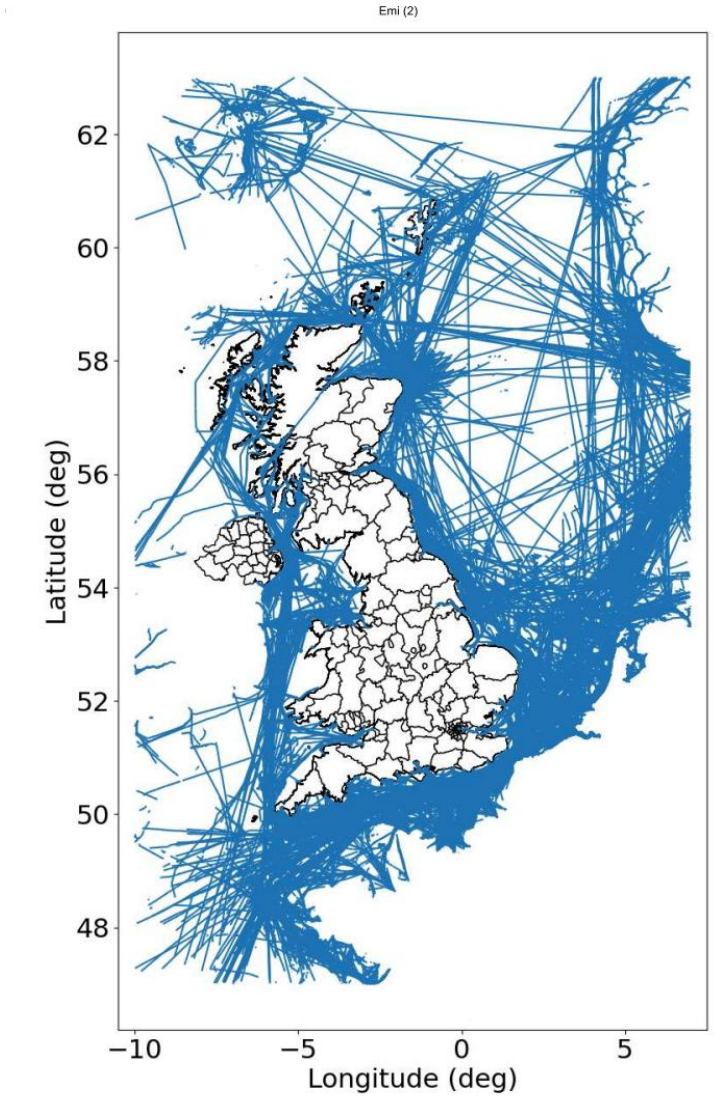
- Combined EO sensors with AI for accurate object detection.
- Reduces false alarms, ensuring accurate monitoring.

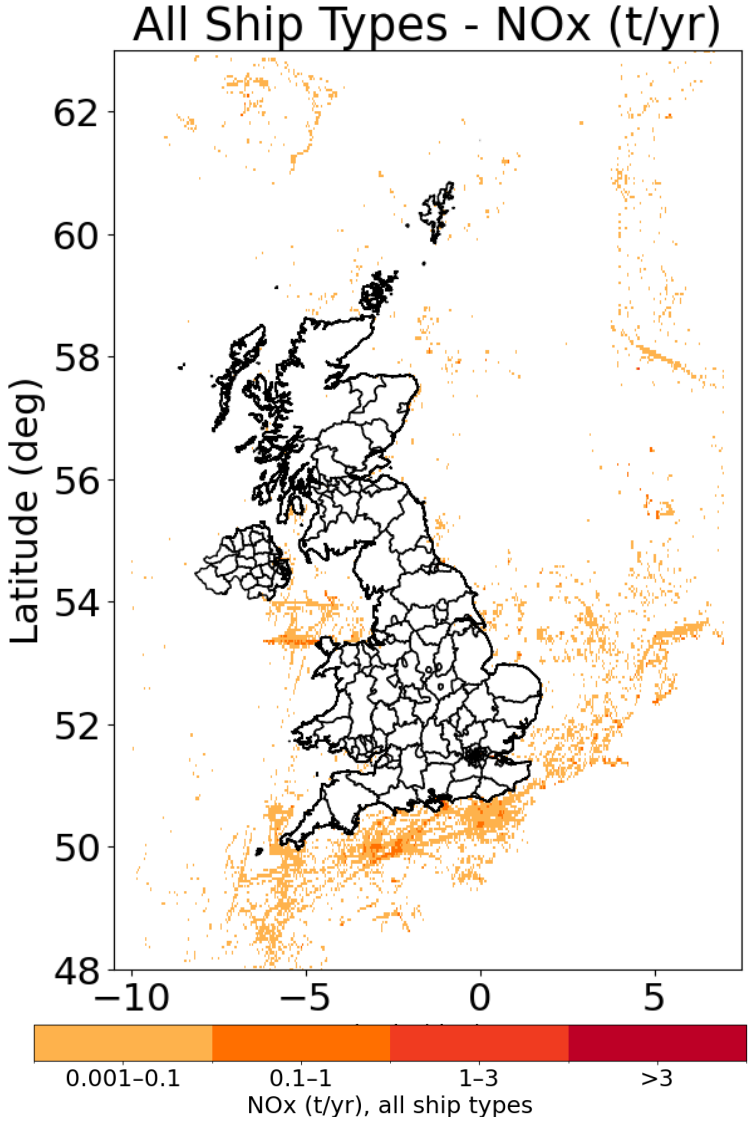
- High accuracy in identifying harmful objects, aiding quick response.
- Detects small, distant objects for early action.

- Rapidly identify environmental risks in marine areas.
- Supports timely interventions to protect marine ecosystems.

Lyu, H., Shao, Z., **Cheng, T.**, Yin, Y., & Gao, X. (2022). Sea-surface object detection based on electro-optical sensors: A review. IEEE Intelligent Transportation Systems Magazine, (3), 1–12.

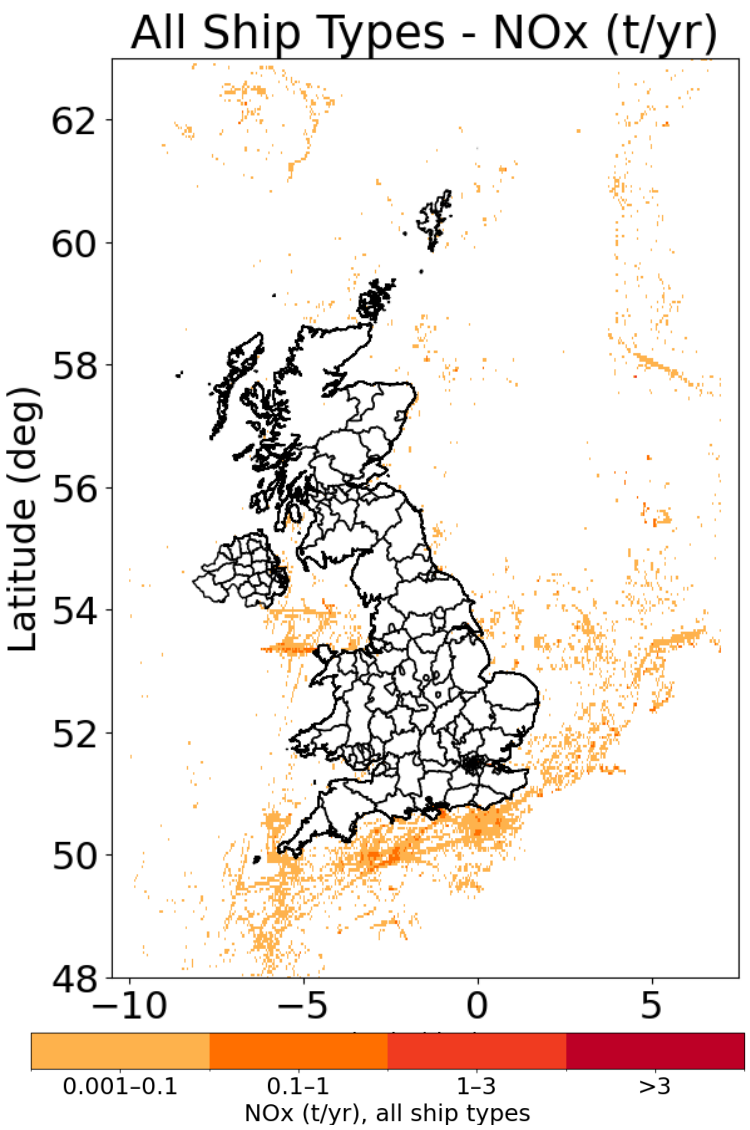
Environmental Protection (T Cheng, J Tang, X Gao, X Zhang 2025)



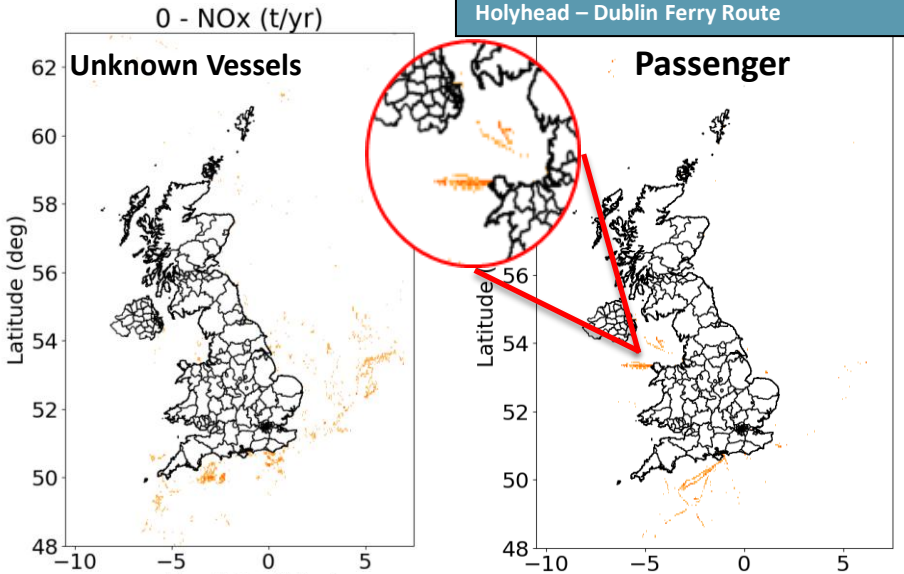


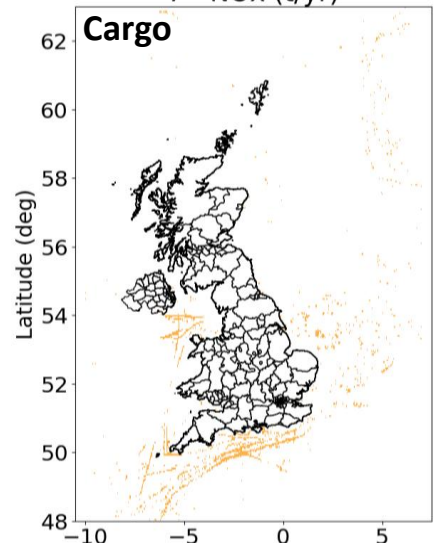
- **NOx emission (5km * 5km)**
- **Time (01.01.2015 - 07.12.2015)**
- **AIS DATA**

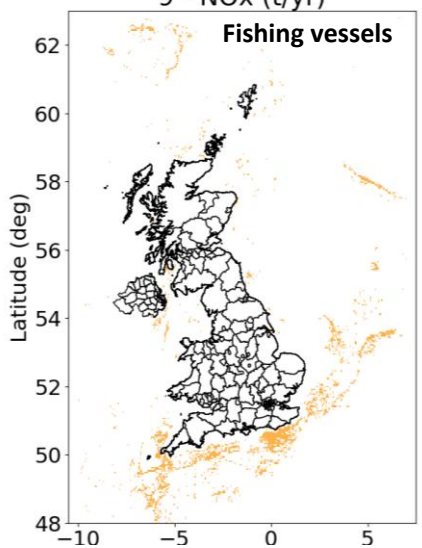
Environmental Protection (T Cheng, J Tang, X Gao, 2025)



Liverpool – Belfast Route
Holyhead – Dublin Ferry Route







- **NOx emission trajectory**

0 - Unknown Vessels

1 - Non-Port service craft

2- Port service craft

3- Vessels engaged in dredging or underwater operations

4 - High Speed Craft

5 - Military or Law enforcement

6 - Passenger

7 - Cargo

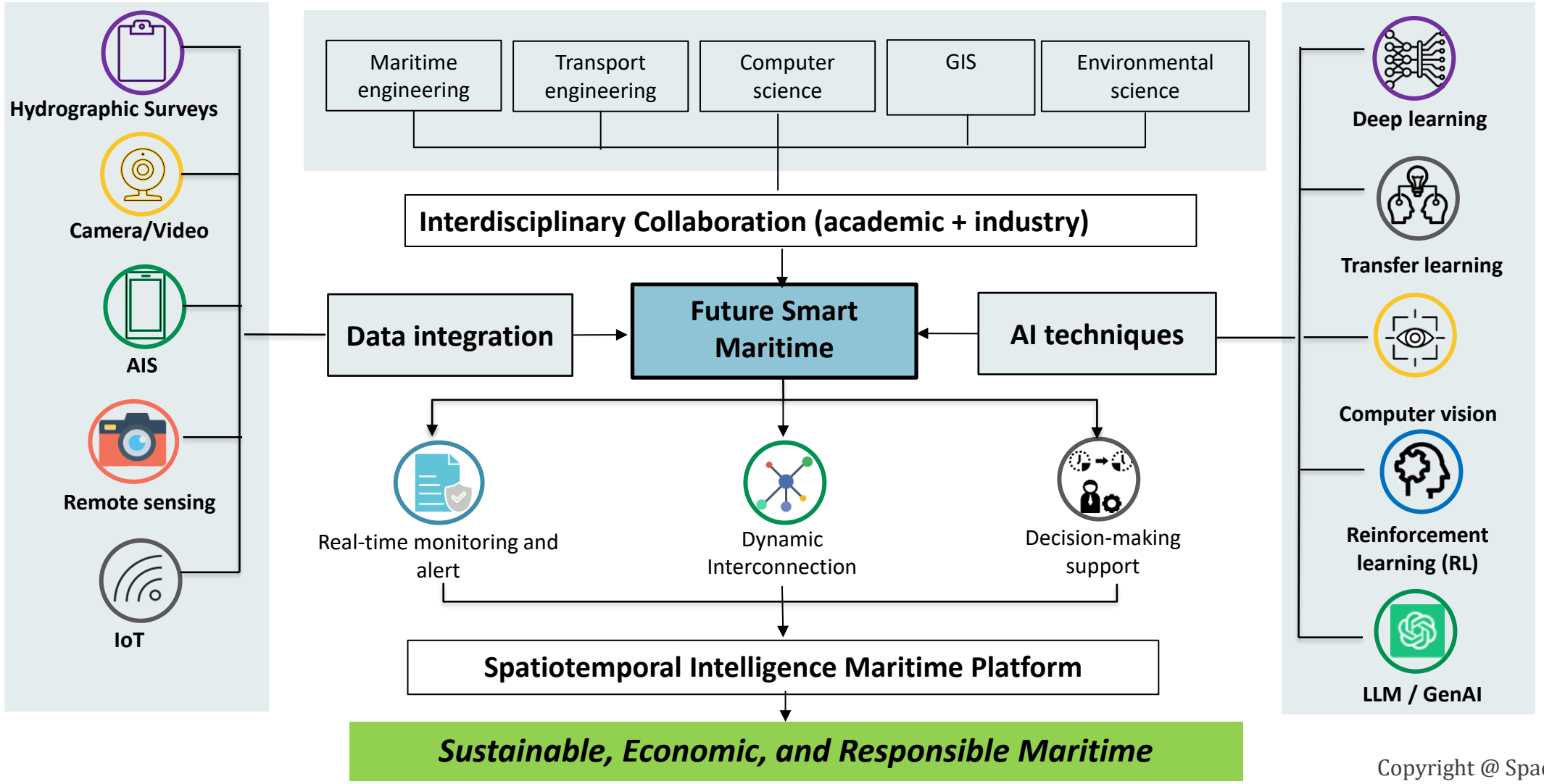
8 - Tankers

9 - Fishing vessels

10 - Recreational vessels

SpatioTemporal AI for Future Maritime

➢ ***Harnessing Data and AI for Smart Maritime Decisions (Digital Twins)***



Acknowledgement

Team of SpaceTimeLab, UCL

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Twitter: @SpaceTimeLab