A Complex Network Approach to Marine Traffic Interaction Modeling: Feature Extraction for Real-Time Traffic Awareness

Julius Venskus [1,3], Robertas Jurkus [2,3], Povilas Treigys [2]
1 Institute of Applied Mathematics, Vilnius University
2 Institute of Data Science and Digital Technologies, Vilnius University
3 Klaipeda University

Marine traffic interaction modelling is critical for improving situational awareness and enhancing safety in maritime operations. This paper presents an approach that leverages complex network theory and feature extraction techniques to model and analyze marine vessel interactions in real-time. Using Automatic Identification System (AIS) data, we construct a dynamic maritime network where nodes represent vessels, and edges capture interaction factors such as proximity, speed and heading correlation, and route similarity. Key network features, including degree centrality, clustering coefficient, and betweenness centrality, are extracted to characterize vessel interactions, offering deeper insights into patterns such as congestion, cooperative navigation, and risk-prone behaviours. Through the application of clustering and network analysis algorithms, we identify distinct interaction types and anomalous activities, enabling real-time predictions of traffic patterns and potential risks. The framework is validated using historical AIS data and maritime incident reports, demonstrating its effectiveness in enhancing real-time traffic awareness for vessel traffic service (VTS) operators and autonomous ship systems. This study offers a solution for modelling marine traffic dynamics and improving decision-making and operational efficiency in increasingly congested and complex maritime environments. This research contributes to the development of advanced tools for real-time maritime traffic management, providing actionable insights that enhance navigational safety and optimize marine operations.

Acknowledgements: This project has received funding from the Research Council of Lithuania (LMTLT), agreement No S-MIP-24-117.

Objectives

- Develop a dynamic maritime network model using AIS data.
- Extract key network features to characterize vessel interactions.
- Identify traffic patterns, anomalous activities, and potential risks.
- Enhance real-time situational awareness for vessel traffic service (VTS) operators and autonomous ship systems.

Methods

Data Acquisition:

- - Automatic Identification System (AIS) data.
- - Historical maritime incident reports.

Network Construction:

- **Nodes:** Represent vessels.
- **Edges**: Capture interaction factors such as:
  - Proximity and collision prediction
  - Speed and heading correlation
  - Route similarity and trajectory similarity and clustering.

Feature Extraction:

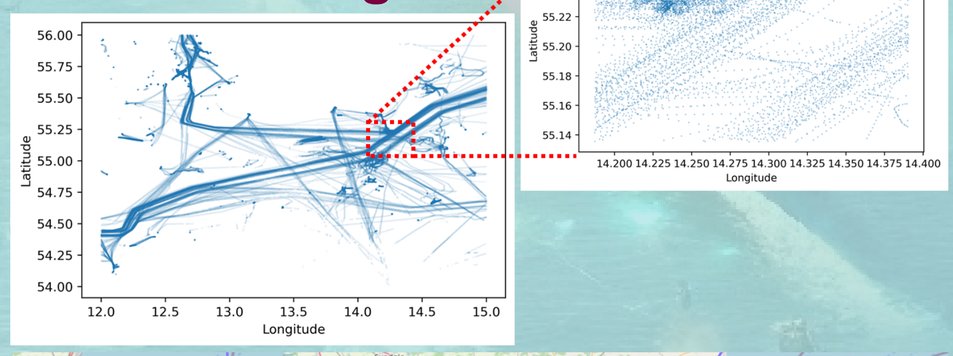
Network Metrics:

- Degree Centrality
- Clustering Coefficient
- Betweenness Centrality

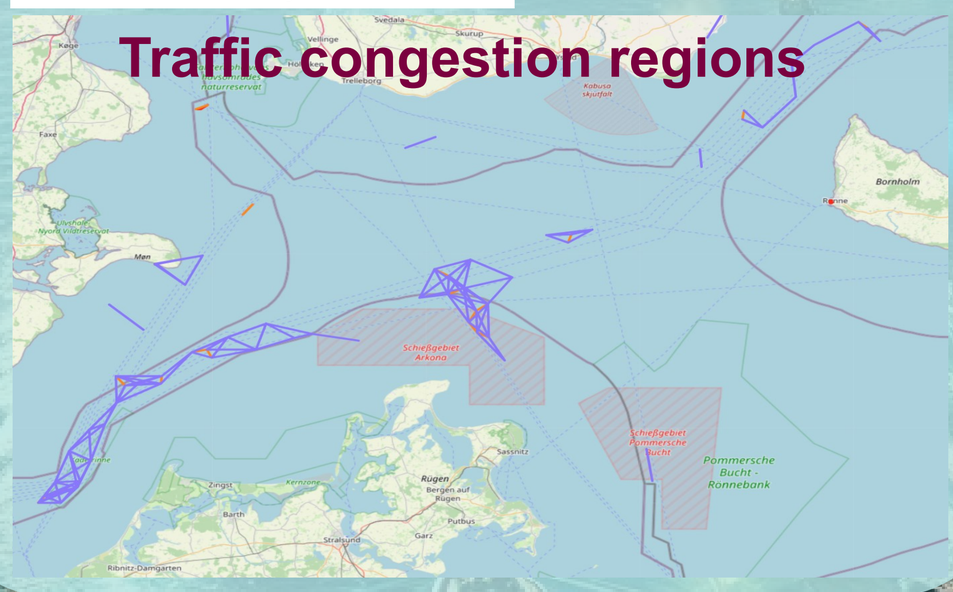
Analysis:

- Clustering and network analysis algorithms.
- Real-time prediction of traffic patterns and risks.

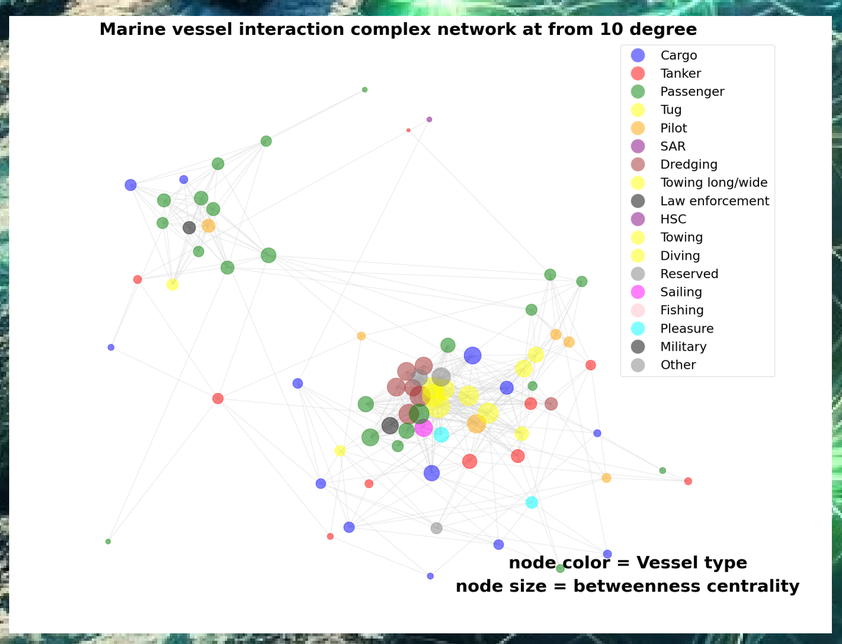
Real case analysis in Bornholm region

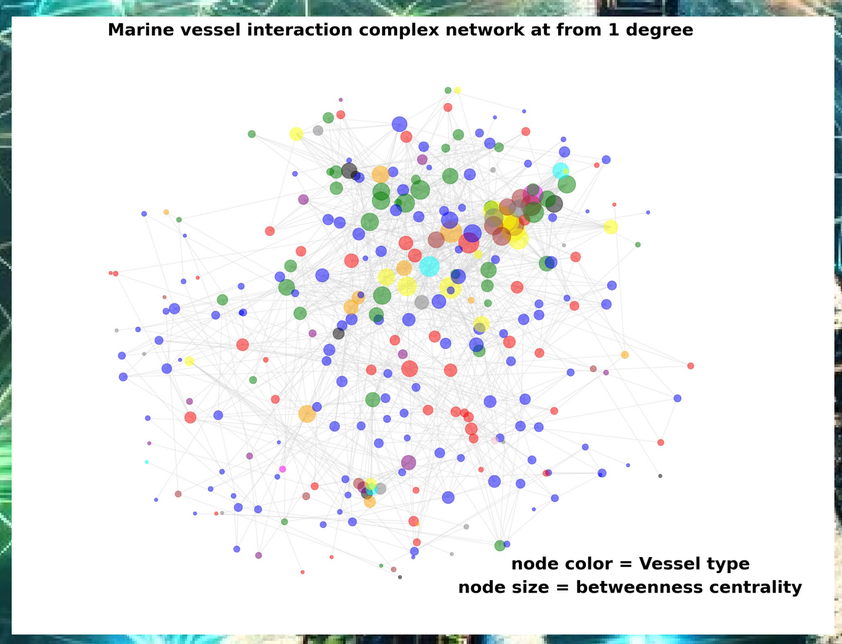


Traffic congestion regions



Marine interaction complex network





Trajectory clustering