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AI for road safety monitoring and crash prediction from micro to macro levels

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IVORY - Project

- **IVORY**
  "AI for Vision Zero in Road Safety"
  ivory-network.eu/
- **Partners**
  4 Universities
  8 Non-academic partners
  13 Associated Partners
  10 Countries
- **Framework Program**
  Within the framework of the Horizon Marie Skłodowska-Curie Actions (**MSCA**), IVORY is an industrial doctorates network, aiming to develop a new framework for the integration of AI in road safety.
- **Objectives**
  - **Responsible and fair AI** for road safety.
  - **Safe road users** and human-vehicle-environment interaction by means of AI.
  - Scalable and equitable AI technologies for **proactive infrastructure safety management**.
  - A sustainable **learning, knowledge sharing and networking platform** on AI for road safety.

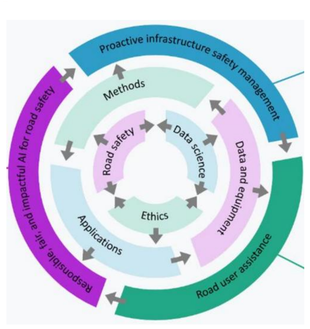

Figure 1: *IVORY pillars*

PhD Goals

- **Objectives**
  - To investigate the effect of **spatial scale** on road safety monitoring and crash prediction.
  - To develop a new **AI framework** to observe and analyze **road safety KPIs** and **predict crashes** by achieving transition from smaller scales to larger ones, considering the time dimension.
  - To assess the **effectiveness** and **scalability** of microscopic road safety models for macroscopic crash prediction and vice versa.
- **Expected results**
  - Evaluation of **several scaling combinations** that will also feature capabilities of 'zooming in/zooming out' of study areas using different levels of telematics.
  - Knowledge on comparable **advantages** and **disadvantages** for each analysis scale.
  - A case study utilising **driver telematics** in an urban area, with actionable results, compatible with the vision and activities of **OSeven** – showcasing the impact of using AI for micro-analysis based on driver telematics and integrating the findings to larger scales.
- **Planned Secondment at EIRA-SI**
  - With the purpose to test the developed methods on additional datasets and countries, with an emphasis on **transferability techniques**.

Methodology

- OSeven Telematics provided telematics data collected via **smartphone hardware sensors** to monitor driver behavior.

Figure 2: *OSeven flow*

- **OpenStreetMap** (OSM) is a free, editable global map created by volunteers and released under an open-content license. It was used to extract a graph, along with node and edge datasets which were preprocessed.
- Telematics features were **aggregated** onto spatial entities from OSM.

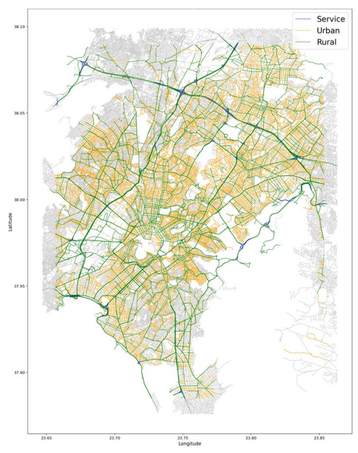

Figure 3: *Telematics Road Network*

- Partitioned data into 2 clusters using **K-Means** to identify underlying group structures.
- Leveraged **Graph Neural Networks** (e.g., Graph Attention Networks) to learn node embeddings capturing relational and topological context.

Results

- Trained a **Graph Attention Network** (GAT) using a contrastive loss to generate node and edge embeddings, enhanced by the **attention mechanism**.

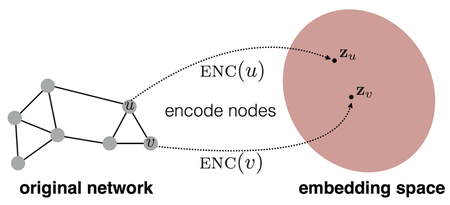

Figure 4: *Node Embedding*

- Applied **clustering** to both raw features and learned embeddings.
- Embeddings improved clustering performance, with higher **Silhouette** scores and lower **Inertia** values.
- Mapped embedding-based cluster labels to raw data, enabling feature averaging per cluster for **interpretability**.
- Identified **risky clusters**, visualized as **red dots** and **red lines** in Figures 5 and 6, representing high-traffic areas with elevated risk indicators.

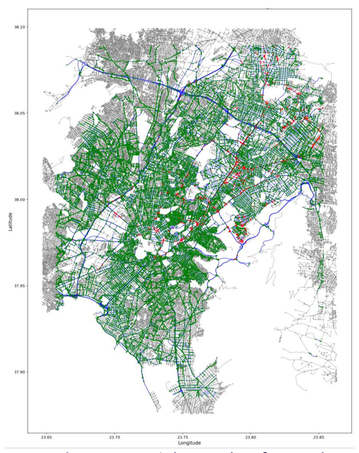

Figure 5: *Risky and safer nodes*

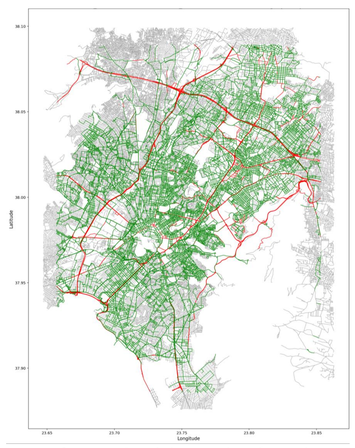

Figure 6: *Risky and safer edges*

Discussion

- The **clear quantitative separation** between node groups validates the use of embedding-based clustering for identifying **meaningful clusters**.
- The magnitude of difference in key supports the **practical relevance** of the classification.
- The results align with known **road safety principles**: higher speeds and distracted driving increase risk.
- Integrating **cluster labels with raw features** and averaging values per cluster bridges the gap between **complex representation learning** and **real-world feature insights**, improving explainability.

Ongoing steps

- Development of a **two-stage hierarchical GNN** model:
  1. It encodes each **municipality's graph** into a single vector embedding using a GNN combined with pooling mechanism.
  2. A second GNN then processes this **super graph**—where nodes represent municipalities and edges reflect shared borders—to generate refined **node embeddings**.
- This hierarchical approach effectively captures both detailed local graph structures and broader spatial relationships, enabling richer, **multi-scale representation learning**.

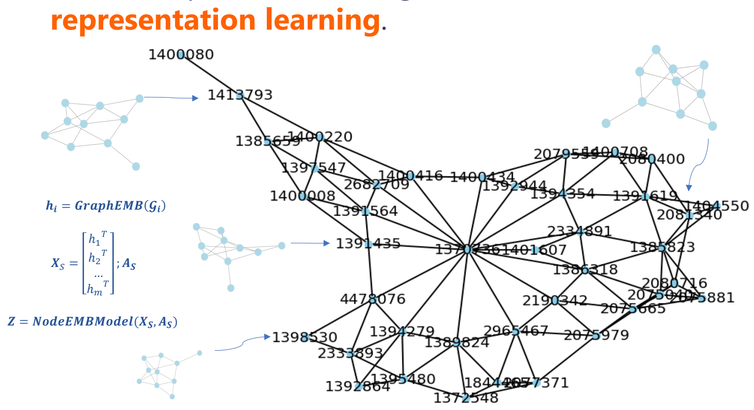

Figure 7: *Visualizing 2-Stage Hierarchical GNN*

Scientific and Social Impact

- This research contributes to **UN SDG Target 3.6** and **Vision Zero** by creating scalable AI models for multi-level road safety monitoring and crash prediction.
- The developed methods offer actionable insights to **Road Authorities**, helping prioritize safety **interventions** in high-risk locations like intersections and critical road segments.
- By testing these models on diverse datasets from multiple countries, the approach ensures **transferability** and **adaptability** across different contexts.

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