International Cartographic Association
Association Cartographique Internationale

HOPE - High-resolution Operational Population Estimation with GNN

Adam Nadolny [a] , Adam Iwaniak [a]

[a] *The Wroclaw Institute of Spatial Information and Artificial Intelligence, Adam Nadolny - adam.nadolny@wizipisi.ai, Adam Iwaniak - adam.iwaniak@wizipisi.ai*

Keywords: population, GNN, drone, Sentinel

Abstract:

The increasing integration of drones into urban airspace presents innovative opportunities but also raises significant public safety concerns and operational challenges. To address these, the Specific Operations Risk Assessment (SORA (Agency, 2025)) frameworkdeveloped by JARUS (initial version in 2019) and mandated by EASAis employed to evaluate and mitigate risks associated with drone missions, particularly in densely populated environments.

Current risk assessments often rely on datasets such as the Global Human Settlement Layer (GHSL Freire (2016)), primarily derived from Landsat data (30 m resolution, with population grids typically at 100 m), although other sources like WorldPop or national statistics are also used. The resolution of GHSL and the level of aggregation in input data may limit the precision of risk modeling, potentially leading to overly conservative flight plansespecially in dense urban areas where fine-grained population distribution is crucial.

To address these limitations, the HOPE project, carried out in collaboration with the European Space Agency, aims to develop a high-resolution (50x50 m) population density layer. This increased granularity, combined with advanced dasymetric mapping techniques for appropriately disaggregating population counts, is intended to support more accurate and nuanced operational planning.

The HOPE methodology integrates diverse open data sources, including building footprints (distinguishing types such as residential/commercial and incorporating volumetric data), topography, orthophotos, transport networks, and public utility points of interest (POIs). It leverages advanced machine learning techniques, particularly Graph Neural Networks (GNNs), to model complex spatial relationships. GNNs are well-suited for capturing interactions between heterogeneous objects (e.g., buildings, roads, POIs), which are critical for human presence patterns that traditional raster-based approaches may overlook.

The research focuses on heterogeneous GNNs (HGNNs), constructing graphs in which initial grid cells (e.g., from GHSL, used as a reference) serve as nodes, with edges defined by neighborhood relationships. This structure is enriched with various node types (e.g., POIs, building types) and relations (e.g., containment, accessibility via transport networks). Transport data are incorporated either as cell attributes or inter-node relations. This enables the computation of contextual cell embeddings that reflect diverse local influences. To ensure scalability across large urban areas (potentially >100k nodes), graph sampling techniquesdrawing on approaches such as GraphSAGE or Cluster-GNNare being considered to manage computational load during the training phase.

The primary research objective is to evaluate how spatial object relationships can be modeled using GNNs for high-resolution population estimation. The methodological foundation draws from the latest GNN research in geoinformatics Kaczmarek et al. (2023) and Yang et al. (2024) , adapting elements such as vector-based geometry encoding where applicable, building on their demonstrated effectiveness in spatial classification and feature extraction. The system is being tested in the city of Wrocaw, which offers a diverse urban structure and thus a robust environment for model evaluation.

Improved population estimation will enable more precise assessments of potential damage, enhancing drone route optimization, safety, and mission feasibility. HOPE aims to balance risk minimization with operational flexibility by improving the granularity and reliability of population density estimates. Figure 1 illustrates a case study where the coarse GHSL resolution may unnecessarily constrain mission points (e.g., near riverbanks), whereas the higher detail offered by HOPEsupported by specific population values and trajectory analysis in the full studyenables more accurate planning.

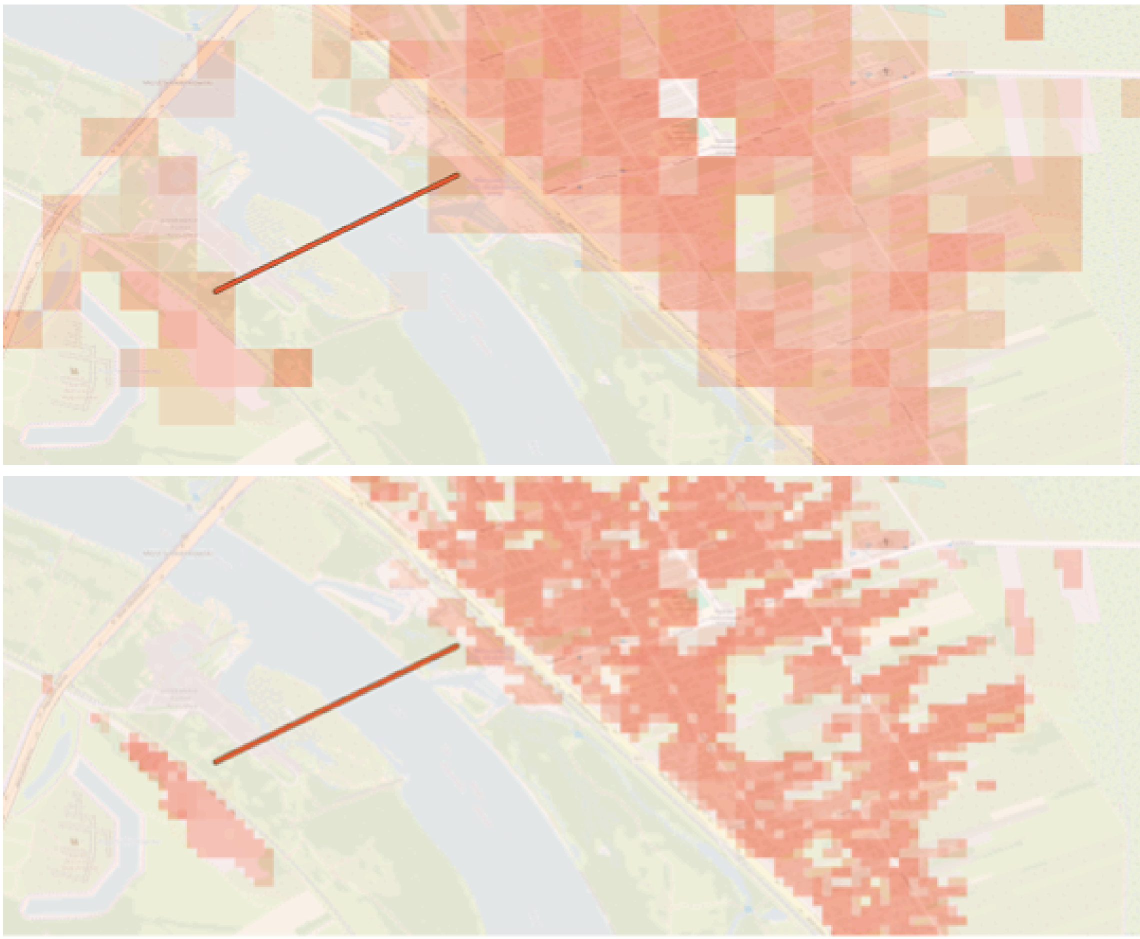

Figure 1. Planned mission trajectory overlaid on the population layer (from top: GHSL, HOPE).

In summary, the HOPE project represents a significant advancement in the safe and efficient integration of unmanned aerial vehicles into complex urban environments, combining high-resolution data with advanced machine learning to support both risk mitigation and operational viability.

Acknowledgements

The authors would like to express their gratitude to the European Space Agency (ESA) for their financial and technical support of the HOPE project.

References

Agency, E. U. A. S., 2025. Specific operations risk assessment (sora). Accessed: 23 January 2025.

Freire, S., 2016. High-resolution population density maps for global human settlement. *Data* 3(3), pp. 16–20.

Kaczmarek, I., Iwaniak, A. and wietlicka, A., 2023. Classification of spatial objects with the use of graph neural networks. *ISPRS International Journal of Geo-Information*.

Yang, B., Zhang, M., Zhang, Z., Zhao, Y. and Gong, J., 2024. Univecmapper: A universal model for thematic and multi-class vector graph extraction. *International Journal of Applied Earth Observation and Geoinformation* 130, pp. 103915.

Abstracts of the International Cartographic Association, 10, 210, 2025
32nd International Cartographic Conference (ICC 2025), 17–22 August 2025, Vancouver, Canada.
https://doi.org/10.5194/ica-abs-10-210-2025