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# Advancing Graph Convolutional Networks to Improve Road Network Selection for Small-Scale Maps

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**Abstract:**

Legibility at smaller scales with preservation of the essential characteristics and structural patterns of an area is the most crucial task. Thus the process of cartographic generalization, relying on level of detail reduction, is fundamental to map design (Kraak et al., 2020). Road networks, which serve as the structural foundation of most general maps, pose a significant challenge for automated selection. This challenge is especially highlighted in the transition from medium scales (1:200,000–1:250,000) to small scales (1:500,000 and smaller), where feature omission rates often reach 60–70%. Such a high degree of reduction creates an unbalanced selection problem. This is also a particularly hard task to automate because it risks disrupting network connectivity or distorting the structural properties of the road system when using machine learning methods (Karsznia et al., 2024; Adolf & Karsznia 2025). While traditional methods such as stroke-based or mesh-based approaches have attempted to preserve network hierarchy, they can struggle with the complex relational structures required for small-scale representations. This research addresses these limitations by advancing a graph convolutional networks (GCN-based) approach that enables a model to learn selection patterns directly from the network's topology.

The proposed methodology utilizes a line graph representation (Porta et al., 2006; Benz & Weibel, 2014). Road segments are enriched with geometric attributes including centrality measures, node closeness and degree, and proximity measures related to settlements and other roads. To capture broader spatial context and provide sufficient amounts of data to train models, higher-order subgraphs are constructed around each segment. The training process utilizes a five-layer GCN optimized with a binary cross-entropy loss function. Furthermore, the topology-guided smoothness regularizer, which penalizes large probability differences between adjacent segments to encourage spatial coherence, is included in the training phase. The process is then supplemented with a connectivity-based post-processing step that identifies and removes isolated, low-confidence network fragments to ensure the resulting output remains structurally consistent.

The effectiveness of this approach was evaluated through experiments conducted on national datasets from Poland (GGOD) and Switzerland (TLMRegio), using national reference maps as the "ground truth" for supervised learning. Models were trained on a country-specific basis to respect unique national classification systems and settlement structures. Preliminary experiments established that an 80/10/10 data split provided the optimal balance of training capacity and evaluation stability across different geographic contexts.

Quantitative results demonstrated that the model performed significantly better on the Swiss dataset, achieving an accuracy of 0.8395 and an F1-score of 0.7232, compared to the Polish dataset's accuracy of 0.6871 and F1-score of 0.6441. Visual analysis revealed that the Swiss selection displayed stronger alignment with the reference maps, capturing dense radial patterns and linear corridors with minimal isolated fragments (figure 1 a).


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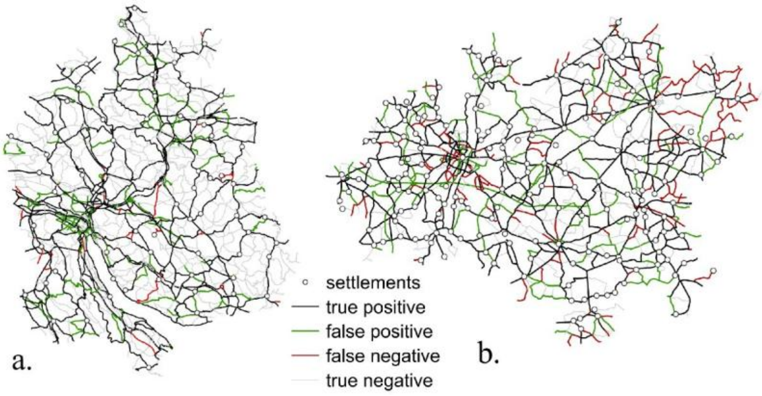


Figure 1. Confusion matrix visualization for (a) Zurich canton (Switzerland) and (b) part of wielkopolskie vivodeship (Poland).

In the Polish case, while the structure of the network remained visible and settlements stayed connected, the GCN tended to produce denser networks than the reference maps, particularly in urbanized zones where multiple parallel connectors were retained (figure 1 b).

The study concludes that GCNs are highly capable of producing topologically consistent generalized road networks. However, the important finding is the discrepancy between statistical metrics and visual coherence; even when accuracy and F1-scores appeared modest, the visual outputs were often interpretable and cartographically acceptable. This suggests that traditional binary classification metrics are insufficient for assessing the quality of cartographic generalization. Furthermore, the model proved capable of identifying meaningful structures even when ground truth data was outdated or contained minor topological inconsistencies. Future advancements should focus on developing integrated evaluation strategies that combine computer vision techniques with graph-based analysis to provide a more robust assessment of result quality.

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**References**

Adolf A., Karsznia I. 2025. Review of road selection methods for the purpose of multiscale mapping. Miscellanea Geographica. Regional Studies on Development, 29(4) pp. 1-15, DOI: https://doi.org/10.2478/mgrsd-2025-0031.

Benz, SA & Weibel, R 2014, ‘Road network selection for medium scales using an extended stroke-mesh combination algorithm’, Cartography and Geographic Information Science, vol. 41, no. 4, pp. 323–339.

Karsznia I., Adolf A., Leyk S., Weibel R. 2024. Using machine learning and data enrichment in the selection of roads for small-scale maps. Cartography and Geographic Information Science, 51(1): 60-78, DOI: 10.1080/15230406.2023.2283075.

Kraak, M. J., Roth, R. E., Ricker, B., Kagawa, A., & Le Sourd, G. (2020). Mapping for a sustainable world. United Nations: New York, NY (USA).

Porta, S., P. Crucitti, and V. Latora. 2006. “The Network Analysis of Urban Streets: A Dual Approach.” Physica A: Statistical Mechanics and Its Applications 369 (2): 853–866. doi:10.1016/j.physa.2005.12.063.


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