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GIS-Based Isochrone Modelling for Transport Accessibility Assessment: Evidence from Sumy Oblast, Ukraine

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SUMMARY

Transport accessibility is a key factor influencing regional integration, spatial equity, and the efficiency of public service provision. Traditional distance-based measures often fail to reflect the actual performance of transport systems, making travel-time-based approaches more suitable for regional accessibility assessment. This study aims to evaluate automobile transport accessibility in Sumy Oblast, Ukraine, through multi-level GIS-based isochrone modelling at both district and regional scales. The methodology is based on weighted graph analysis, where territorial community centres are represented as nodes and road connections as weighted edges corresponding to estimated travel times. Shortest travel times were calculated using Dijkstra's algorithm, while continuous accessibility surfaces and isochrone maps were generated through spatial interpolation. The entire analytical workflow was implemented using open-source GIS and Python-based tools, ensuring transparency and reproducibility. The results reveal substantial spatial disparities in transport accessibility across Sumy Oblast. District-level analysis demonstrates considerable differences in accessibility patterns associated with the geographical position of district centres, transport network configuration, and natural barriers. Regional-scale modelling identifies a pronounced centre–periphery gradient, with communities surrounding the regional centre exhibiting the highest accessibility, whereas northern border communities experience the longest travel times. The comparison of district and regional accessibility demonstrates that efficient connectivity within a district does not necessarily ensure favourable accessibility to the regional centre. The study confirms that GIS-based multi-level isochrone modelling provides a robust and transferable framework for identifying spatial inequalities in transport accessibility and supports evidence-based regional planning, infrastructure prioritisation, and territorial decision-making.

Keywords: GIS; Isochrone modelling; Transport accessibility; Spatial analysis; Regional planning; Graph analysis; Dijkstra algorithm; Sumy Oblast; Territorial communities.

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Introduction

Transport accessibility represents one of the key determinants of regional cohesion, influencing the efficiency of public administration, economic interactions, and residents' access to essential services. In recent years, Geographic Information Systems (GIS) have become an important tool for analysing spatial accessibility, enabling the integration of transport networks, geospatial data, and travel-time modelling into comprehensive decision-support frameworks. Among contemporary GIS techniques, isochrone modelling has proven particularly effective for representing spatial inequalities in accessibility and identifying territories with limited transport connectivity. Following the administrative-territorial reform in Ukraine, the organisation of transport accessibility has acquired additional significance due to the formation of new districts and territorial communities. Although numerous studies have investigated accessibility to individual urban centres or transport corridors, considerably less attention has been paid to the hierarchical organisation of transport accessibility within regional settlement systems, where residents interact with both district and regional administrative centres. Sumy Oblast provides an appropriate case study because of its heterogeneous settlement pattern, substantial spatial extent, and pronounced differences in road network configuration between central and peripheral areas. These characteristics create significant spatial disparities in travel time that cannot be adequately explained by Euclidean distance alone.

The purpose of this study is to assess the hierarchical transport accessibility of territorial community centres in Sumy Oblast using GIS-based isochrone modelling. The research analyses accessibility at two spatial levels – towards district centres and the regional centre – and identifies spatial patterns of accessibility that may support regional planning and evidence-based transport management.

Transport accessibility has become one of the key concepts in transport geography and regional planning, reflecting the ability of people to reach activities and services within a given travel time. Hansen's pioneering work introduced accessibility as the potential for spatial interaction, establishing the theoretical foundation for subsequent accessibility research (Hansen, 1959). Later was demonstrated that accessibility is a multidimensional concept determined not only by transport infrastructure but also by the spatial distribution of opportunities and population characteristics (Geurs & van Wee, 2004). Recent advances in Geographic Information Systems (GIS) have considerably expanded the possibilities for accessibility assessment through travel-time modelling. Among these approaches, isochrone analysis has become one of the most widely applied methods for representing spatial inequalities in accessibility. Apparicio et al. demonstrated the effectiveness of isochrone mapping for evaluating access to public services, while their later methodological review highlighted the importance of selecting appropriate distance and travel-time measures for spatial accessibility analysis (Apparicio et al., 2008; 2017). Many studies increasingly rely on high-resolution transport network data, open-source GIS tools, and web-based routing services to produce realistic accessibility models. UrbanAccess (Blanchard & Waddell, P. 2017), illustrates the growing use of open and scalable GIS frameworks for transport accessibility modelling. GIS-based accessibility assessment has become an essential component of evidence-based transport planning and spatial decision-making, providing planners with practical tools for evaluating territorial disparities and supporting infrastructure investment priorities (Papa et al, 2015).

Despite these methodological advances, relatively few studies have investigated hierarchical transport accessibility within regional settlement systems by simultaneously considering accessibility to district and regional centres. This study addresses this gap by applying multi-level GIS-based isochrone modelling to assess transport accessibility across Sumy Oblast.

Method

The study applies an isochrone-based GIS approach to assess automobile transport accessibility at two complementary spatial levels: accessibility of territorial community centres to their respective district centres and accessibility of all community centres to the regional centre (Sumy). Such a multi-level framework enables comparison of accessibility patterns across administrative scales and reveals how

spatial hierarchy influences regional connectivity. The transport network was represented as a weighted graph in which territorial community centres were treated as nodes and road connections as weighted edges. Edge weights corresponded to estimated travel time calculated under an assumed average travel speed of 50 km h^{-1}. Shortest travel times between the source node and all remaining nodes were computed using Dijkstra's shortest-path algorithm, a well-established method for solving optimal routing problems in weighted transport networks (Dijkstra, 1959). To improve the realism of regional accessibility assessment, travel distances were expressed as conditional road distances rather than straight-line or purely geometric distances. Actual road lengths were adjusted using coefficients reflecting road hierarchy and quality, accounting for differences in functional road categories and expected travel conditions. This approach provides a more realistic approximation of regional mobility than Euclidean distance alone.

Travel-time values obtained from the network analysis were interpolated into continuous accessibility surfaces using the cubic interpolation method. Isochrones were generated at 30-minute intervals for the regional accessibility model and at 15-minute intervals for district-level analyses, allowing consistent comparison of accessibility gradients across different territorial scales. All calculations were performed in Python using the NetworkX library for graph analysis, SciPy for spatial interpolation, and Matplotlib for cartographic visualisation. The complete analytical workflow was implemented in Google Colab, ensuring computational reproducibility and transparency.

Results

The GIS-based isochrone modelling revealed pronounced spatial heterogeneity in automobile transport accessibility across Sumy Oblast at both district and regional scales. The generated travel-time surfaces clearly demonstrate that accessibility patterns are determined not only by geographical distance but also by the spatial configuration of the road network, the location of administrative centres, and the overall morphology of the regional transport system. At the district level, considerable differences were identified among the five administrative districts. Sumy District exhibits the highest level of accessibility owing to the central location of the district centre and the concentration of major transport corridors. Most territorial community centres are situated within the 30–60-minute travel-time zone, indicating a relatively balanced spatial structure and efficient internal connectivity. Romny District demonstrates a similarly favourable accessibility pattern. The district centre occupies a relatively central geographical position, while the road network ensures comparatively uniform travel times across the territory. Only the peripheral community of Synivka falls outside the dominant accessibility zone.

In contrast, Konotop and Shostka districts display substantially greater spatial disparities. Both districts possess elongated territorial configurations, which increase travel times from peripheral communities to the district centres. In Konotop District, Putyvl and Nova Sloboda require more than one hour of travel, whereas in Shostka District the most remote communities – including Seredyna-Buda, Znob-Novhorodske, and Khutir-Mykhailivskyi – are characterised by the lowest levels of accessibility. These patterns are further intensified by natural barriers, particularly the limited number of bridges across the Seim River, which constrain network permeability and increase effective travel times. Okhtyrka District represents an intermediate case. Although several neighbouring communities are accessible within 30 minutes, travel times increase rapidly towards the district periphery. Interestingly, Kyrykivka illustrates that relatively short geographical distance does not necessarily imply high accessibility, reflecting the decisive influence of road infrastructure quality rather than Euclidean distance alone.

The regional-scale analysis, based on accessibility from all 51 territorial community centres to the regional capital of Sumy, reveals an even stronger centre-periphery pattern (Figure 1). Communities located in the central part of the oblast generally require less than one hour to reach the regional centre. Accessibility gradually decreases towards the northern and north-western border areas, where travel times frequently exceed two hours and, in several cases, approach or exceed three hours. The most favourable accessibility is observed for communities located within the immediate influence

zone of Sumy, including Sad, Bezdryk, Verkhnia Syrovatka, Stepanivka, Nyzhnia Syrovatka, and Mykolaivka communities. These settlements form a compact high-accessibility belt surrounding the regional capital. Conversely, the lowest accessibility characterises the northern border communities of Znob-Novhorodske, Seredyna-Buda, Druzhba, Svesa, and Yampil, where considerable distance from the regional centre combines with the peripheral configuration of the transport network.

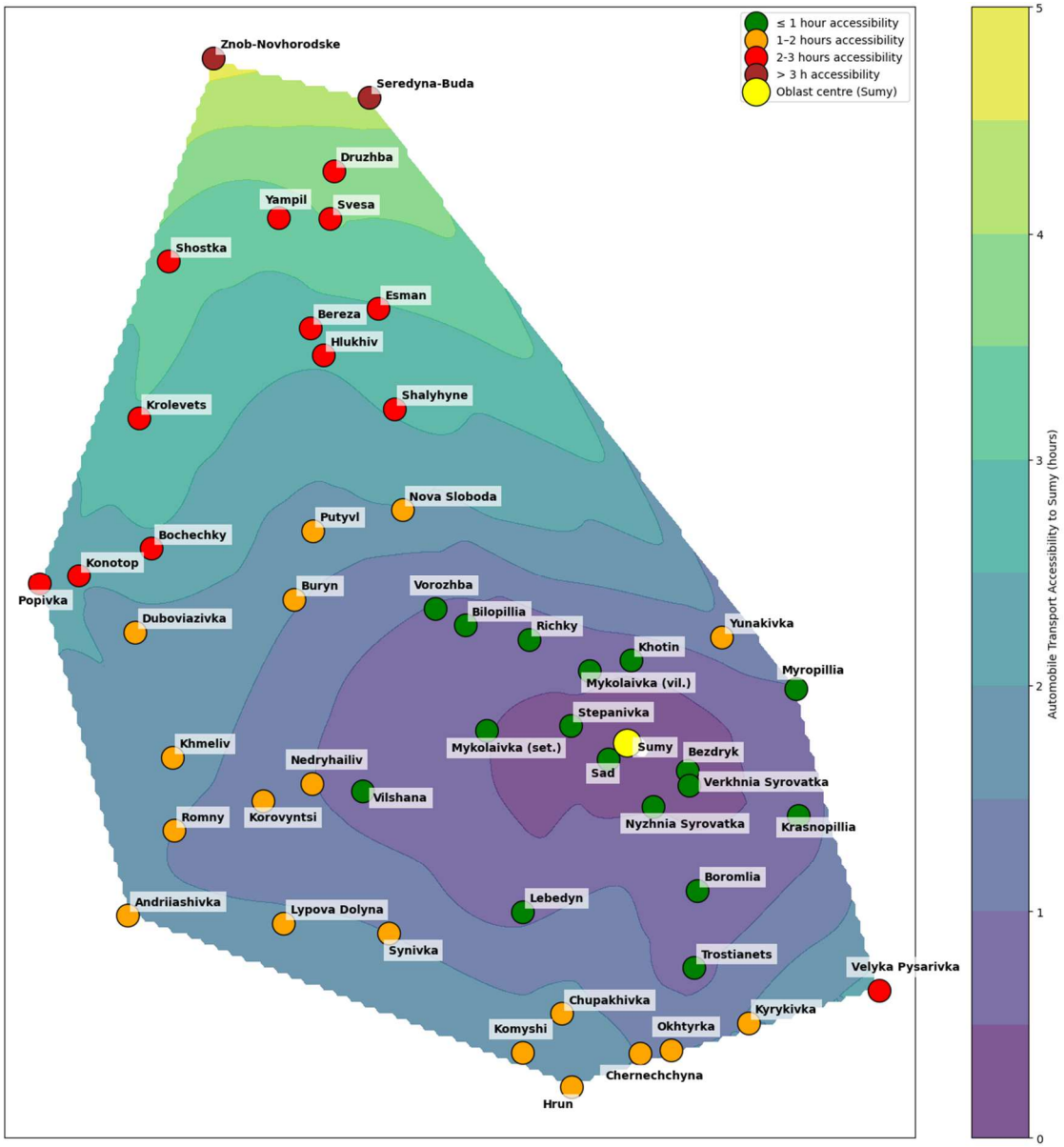

Figure 1. *Isochrone Map of Automobile Transport Accessibility to Sumy*

The comparison between district-level and regional accessibility demonstrates that efficient access to a district centre does not necessarily guarantee efficient accessibility to the regional centre. Several communities function effectively within their district transport systems while simultaneously remaining relatively isolated at the regional scale. This finding highlights the importance of multi-level accessibility assessment, since different administrative levels reveal different dimensions of spatial integration.

The proposed GIS-based isochrone approach effectively visualises accessibility inequalities that cannot be identified using distance-based measures alone. The integration of weighted transport networks with continuous isochrone surfaces provides an intuitive representation of regional mobility patterns and allows peripheral territories requiring priority infrastructure improvements to be

identified. The results demonstrate the applicability of the proposed methodology for regional planning, transport infrastructure assessment, and evidence-based territorial decision-making.

Conclusions

This study demonstrates that GIS-based isochrone modelling provides an effective framework for assessing transport accessibility at multiple administrative levels. By using travel time instead of geographical distance, the proposed approach captures the functional organisation of the regional transport network and reveals spatial inequalities that remain hidden in conventional distance-based analyses. The results show that transport accessibility is inherently a multi-level spatial phenomenon. Accessibility patterns differ substantially between district and regional scales, indicating that efficient connectivity within a district does not necessarily ensure favourable accessibility to the regional centre. This hierarchical perspective extends traditional accessibility assessment and provides a more comprehensive understanding of regional transport organisation.

The analysis identified pronounced centre–periphery gradients across Sumy Oblast. Peripheral communities, particularly in the northern border zone, experience the lowest levels of accessibility due to the combined influence of settlement distribution, transport network configuration, and infrastructure constraints. These findings provide an evidence base for infrastructure prioritisation, spatial planning, and optimisation of public service provision. From a methodological perspective, the proposed graph-based GIS workflow, combining weighted network analysis, Dijkstra's shortest-path algorithm, spatial interpolation, and cartographic visualisation, represents a transparent, reproducible, and transferable approach that can be readily applied to other regions and to different categories of public services. Future research should incorporate dynamic travel conditions, multimodal transport systems, and real-time navigation data to improve travel-time estimation and further strengthen the application of GIS-based accessibility modelling for evidence-based regional decision-making.

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