University of Pardubice

Faculty of Transport Engineering

ORGANISATION OF TRANSPORT SERVICES IN SPARSELY POPULATED AREAS

DISSERTATION THESIS

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Introduction

This dissertation addresses the issue of transport services provision in sparsely populated areas. A sparsely populated area is generally understood as a territory with low population density. Typically, these include small municipalities located in peripheral parts of regions, agricultural areas, and border regions. Sparsely populated areas are characterized by specific features such as an unfavourable demographic structure, limited access to education and employment opportunities, and reduced quality of healthcare; all of these factors significantly influence transport demand. Transport service provision contributes to the sustainable development of a territory. Ensuring transport service provision is a fundamental task of public transport. However, low population density leads to low vehicle occupancy rates or even to the underutilization of public transport services. This subsequently results in the cancellation of public transport services due to their lack of economic viability. The objective of this dissertation is to present proposals that will contribute to improving transport service provision in sparsely populated areas.

1 Status of the studied issue

A sparsely populated area is generally understood as a territory with low population density. Typically, this refers to small municipalities in peripheral parts of a region, agricultural areas, and border regions (1). However, there is no universally accepted definition, nor is there a precise threshold for population size or density that delineates the concept of a sparsely populated area. In the dissertation, the author establishes the following criteria for identifying sparsely populated areas:

- population density,
- distance from the regional centre,
- economic, social and demographic indicators,
- infrastructure and service accessibility,
- environmental and geographic factors.

Transport needs in sparsely populated areas are influenced by the specific characteristics of these regions (2). These characteristics include, for example, low population density, the dispersion of inhabitants into smaller municipalities or isolated settlements, and limited access to education or employment. These socio-economic factors are, among other things, affected by poor accessibility to transport services.

Transport services in sparsely populated areas represent a key factor influencing residents' quality of life and the economic development of regions. The requirement to ensure transport services is based on Regulation (EC) No. 1370/2007 of the European Parliament and of the Council on public passenger transport by rail and by road, in its latest consolidated version (3). Providing high-quality public transport coverage (with connections to surrounding centres) in sparsely populated areas can slow down or even halt the trend of depopulation (4).

Ensuring transport services represents a key factor for the very existence and territorial development of sparsely populated areas. In these regions, transport services are generally provided by public bus services and passenger rail transport. Methods of providing transport services in sparsely populated areas (excluding private car transport) can be categorized into conventional public transport models, demand-responsive transport (DRT), or shared transport (carpooling). The comparison of the different methods of providing transport services is shown in Table 1.

Table 1 The Comparison of Methods for Providing Transport Services

Types of Transport Services	**Territorial Accessibility**	**Flexibility**	**Economic Efficiency**
Public transport	YES	NO	NO
DRT	YES	YES	YES
Carpooling	NO	YES	YES

Source: author

Conventional transport service models ensure the accessibility and coverage of a given area through public transport lines (if they exist in the area). However, their flexibility is low, as they operate according to fixed timetables and permanent routes, which do not account for current or variable travel demand.

Demand-responsive transport ensures accessibility and coverage even in remote areas, based on passenger requests. It is characterized by high flexibility, as routes and departure times are adapted to travel demand.

Shared transport in sparsely populated areas has limited potential in terms of territorial accessibility and coverage. Its implementation depends on the willingness and ability of residents to participate and provide transport, which leads to uneven territorial coverage. On the other hand, flexibility is high, as departure times and routes can be easily adjusted to meet the participants' travel needs.

For the analysis of the state of scientific knowledge on transport services in sparsely populated areas abroad, the author selected European countries. Countries from other continents (e.g., China, the United States, or Australia) were not considered, as they differ significantly from the Czech Republic in terms of territorial size, characteristics of sparsely populated areas, and transport services.

The author primarily chose countries neighbouring the Czech Republic that are also members of the European Union, namely the Federal Republic of Germany, the Slovak Republic, the Republic of Austria, and the Republic of Poland. These countries were selected due to the similarity of the characteristics of their sparsely populated areas, transport, and transport services to those of the Czech Republic. Outside the European Union, the author included the Swiss Confederation, which has a highly developed public passenger transport system. (5, 6, 7, 8 9)

In the European countries analysed by the author, transport services in sparsely populated areas are also generally provided by public transport.

However, there are various alternative approaches to providing transport services, such as:

- public transport on demand (Polish Republic),
- DRT systems – demand-responsive transport (Federal Republic of Germany, Republic of Austria),
- shared transport systems (Federal Republic of Germany, Swiss Confederation).

These alternative options require high investment and operational costs. When organizing transport services in sparsely populated areas, it is always necessary to consider local conditions and the specific characteristics of the studied area.

2 Objective of the Dissertation

The author defined the objective of the dissertation based on conclusions derived from an analysis of scientific knowledge concerning transport service provision in sparsely populated areas in selected European countries and in the Czech Republic. **The aim of the dissertation is to propose and verify a mathematical–graphical model for the organization of transport service provision in sparsely populated areas.**

The partial steps to achieve this objective are focused on defining and delimiting the concept of sparsely populated areas, improving the transparency and efficiency of the system for organizing transport service provision in sparsely populated areas, ensuring the efficient utilization of the vehicle fleet, and securing the accessibility of sparsely populated areas by public transport.

3 Solution methods

For the solution of the given problem, the following methods were applied in the dissertation: multicriteria decision-making methods, network analysis, graph theory methods, vehicle-to-line assignment, algorithmizing methods, and SWOT analysis. Network analysis was carried out using the Microsoft Project software.

Multicriteria decision-making methods are employed to select suitable vehicles for transport services in sparsely populated areas. The TOPSIS method and the WSA method are applied due to their ability to compare heterogeneous and variable data (criteria) through normalization. To determine the weights of individual criteria, the author used the pairwise comparison method in the dissertation.

Network analysis methods, specifically the Critical Path Method, were used by the author in the design part of the dissertation when planning transport services in sparsely populated areas. Activities related to the implementation of the proposed measures are illustrated in the dissertation using a Gantt chart. For this purpose, the author employed the Microsoft Project software.

In the design part of the dissertation, the author also applied Graph Theory, specifically Kruskal's algorithm, which is used to determine the minimum spanning tree of a graph. The graph theory method was employed in the dissertation to identify the backbone network of public transport and to determine appropriate route alignments for public bus services.

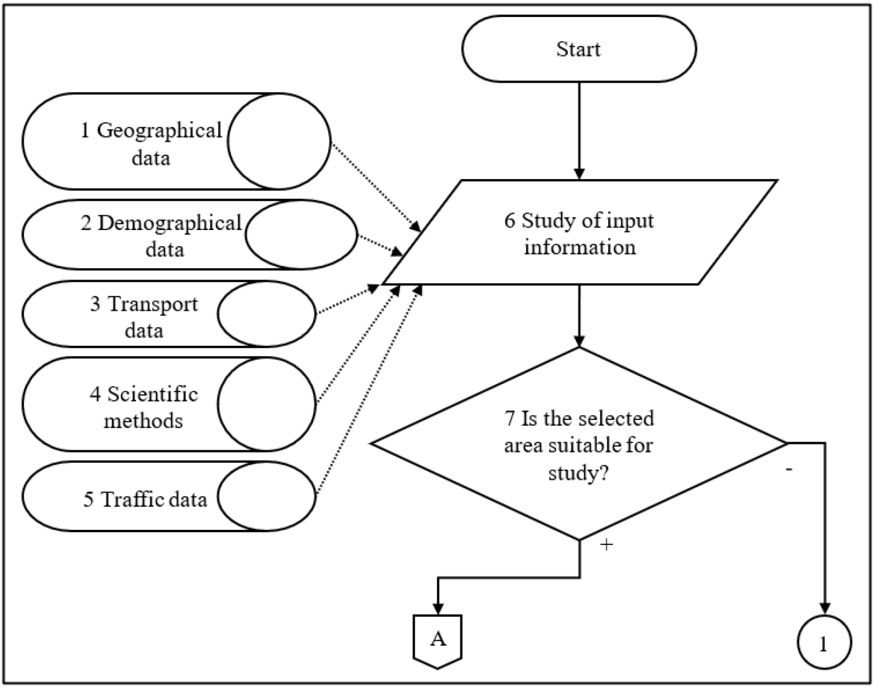
Furthermore, algorithmizing methods were applied, with their output presented in the form of a flowchart. A flowchart represents a graphical illustration of a process, algorithm, or workflow. In the dissertation, the flowchart was used to depict activities and processes involved in the design of a mathematical–graphical model for transport services in sparsely populated areas.

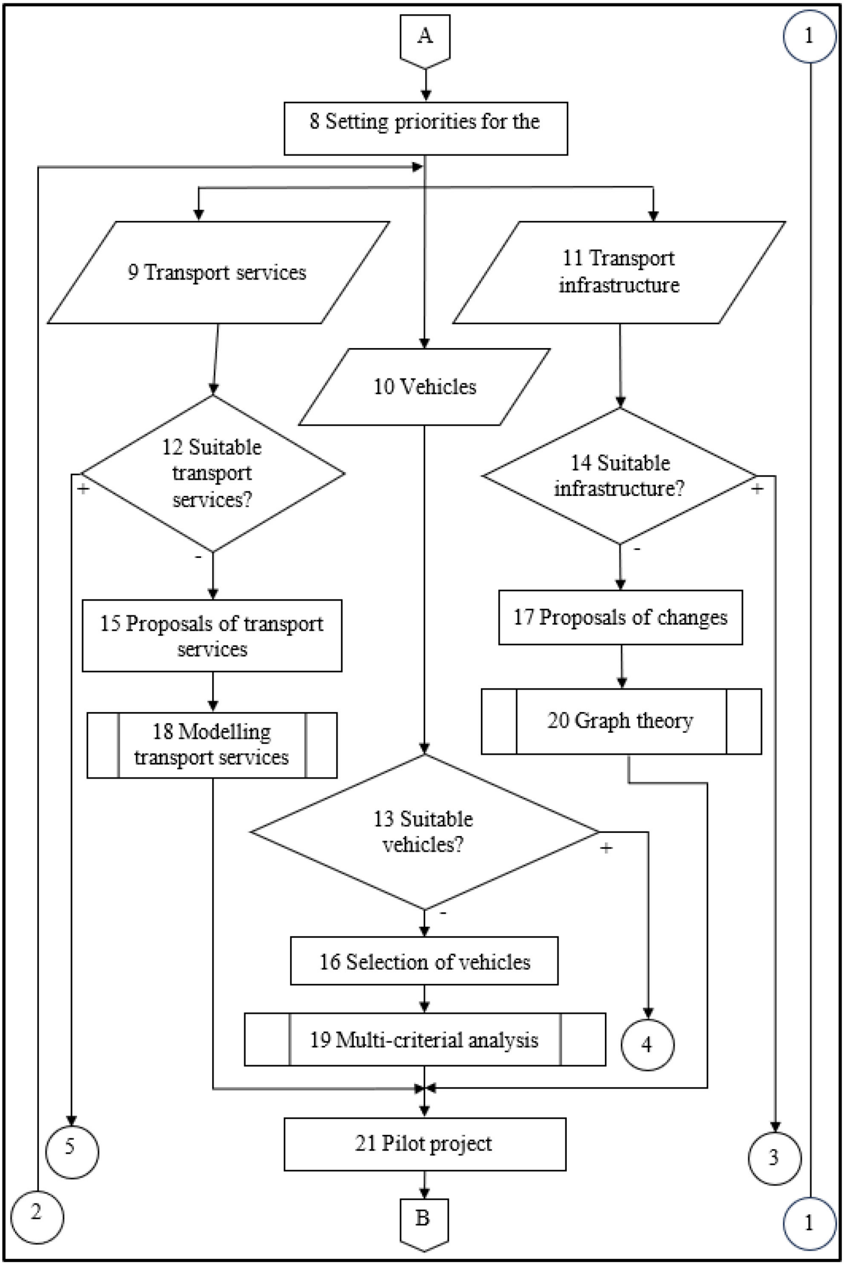
In the analytical part of the dissertation, the SWOT analysis is used to assess the current state of transport services in a sparsely populated area in the Šumava region. The TOWS matrix is employed as one of the supporting tools for determining priorities in addressing transport services in sparsely populated areas within the design part of the dissertation.

The scientific methods and their application were selected with regard to the specifics of transport services in sparsely populated areas. The use of these methods serves to design an effective, functionally integrated, and practically applicable mathematical–graphical model of transport services in sparsely populated areas.

4 Achieved results

The main outcome of the dissertation is the proposed mathematical–graphical model of transport services in sparsely populated areas. This model is illustrated by a flowchart shown in Figure 1. The flowchart consists of 27 blocks in addition to the start and end. It contains a total of 5 blocks for loading input data and information, 4 blocks for studying input information required for the given activity, 6 decision blocks, 8 activity blocks, 4 procedure blocks.




A
1
8 Setting priorities for the
9 Transport services
11 Transport infrastructure
10 Vehicles
12 Suitable transport services?
+
-
14 Suitable infrastructure?
+
-
15 Proposals of transport services
17 Proposals of changes
18 Modelling transport services
20 Graph theory
13 Suitable vehicles?
+
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16 Selection of vehicles
19 Multi-criterial analysis
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21 Pilot project
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B
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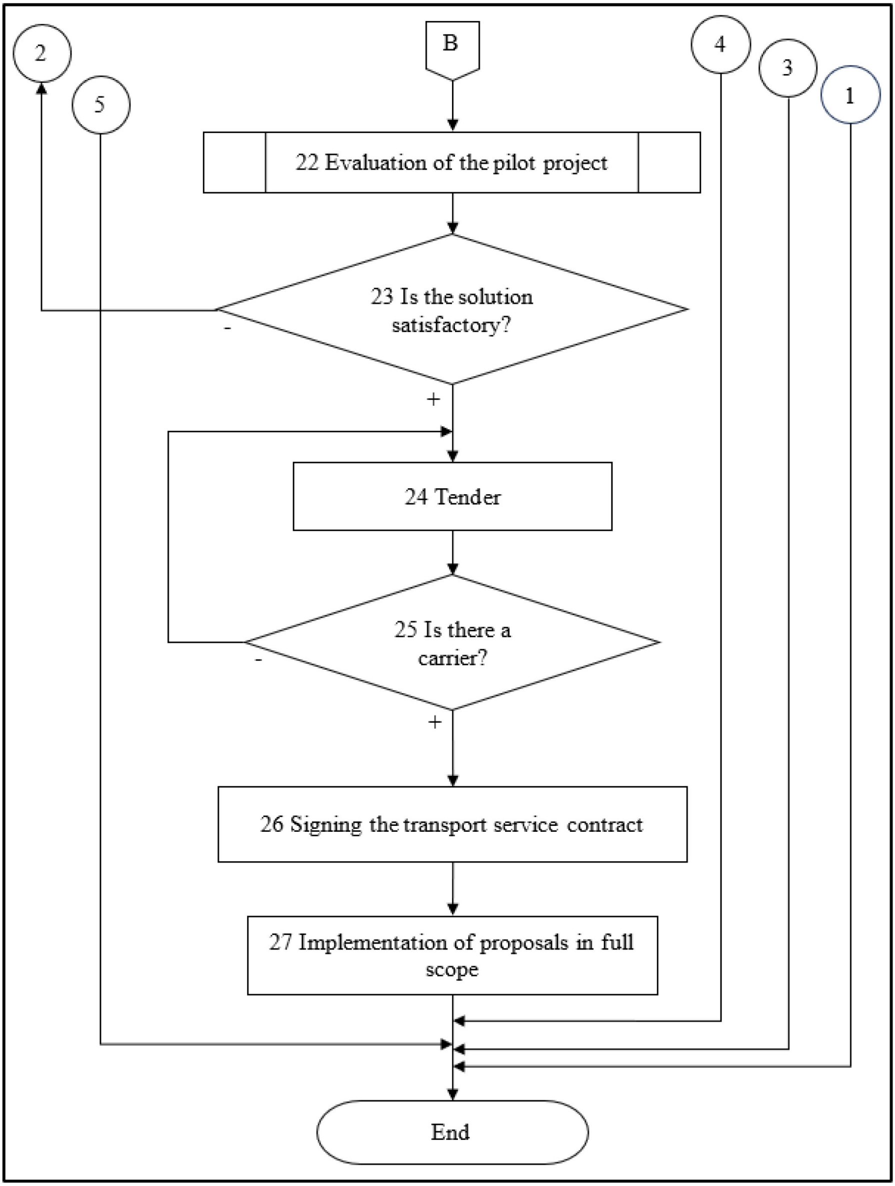

Figure 1 Flowchart of the Proposed Mathematical–Graphical Model

Source: author

To assess the suitability of a given area for addressing transport services, the author proposes a procedure in which individual municipalities are evaluated based on selected assessment criteria, their weights according to importance, and a point scoring system. The main parameter is the evaluation of the area's accessibility by public mass transport in relation to the regular transport needs of local residents (school, work, healthcare, etc.).

To evaluate the transport accessibility of a given area, the author used criteria such as the number of inhabitants, the number of lines and services on a typical working day, travel time to the regional centre, walking distance to the nearest stop etc.

The overall score D_x, representing public transport accessibility for each municipality individually, is calculated based on the weighted sum of point values for the individual criteria according to Formula 1.

$$D_x = \sum_{i=1}^{n} b_i \cdot v_i \; ; i = 1, 2, 3, \dots n \quad \text{[number of points]} \tag{1}$$

where:

D_x … transport accessibility score for a given municipality x [number of points],

b_i … points assigned under the i-th criterion [number of points],

v_i … weight of the i-th criterion [-],

i … individual criteria [-],

n … number of criteria [number].

According to the calculated overall accessibility score (D_x), municipalities are divided into four categories: excellent accessibility, good accessibility, limited accessibility, and inadequate accessibility. This is also reflected in the colour coding of the municipalities on the map.

The maximum score that can be achieved is 8.75 points, while the minimum is 0 points. Municipalities with excellent accessibility (score 8.75–7.51) will be marked in green. Municipalities with good public transport accessibility will be marked in yellow (score 7.51–5.76). Municipalities with limited accessibility (score 5.75–3.76) will be marked in orange. Municipalities with inadequate transport accessibility (score 3.75–0) will be marked in red.

Based on the resulting values of the transport accessibility index D_x, municipalities in the studied area are classified into categories according to the level of transport services. Municipalities with limited or inadequate transport accessibility can be considered a priority for the design and testing of demand-responsive transport (DRT) systems. In line with this assessment, the author proposes two variants for providing transport services using DRT systems:

- **Variant 1** – DRT as a supplement to the existing public bus services (semi-flexible DRT),
- **Variant 2** – DRT as the primary form of transport service in the area (fully flexible DRT).

The schematic of the proposed transport service variants is shown in Figure 2.

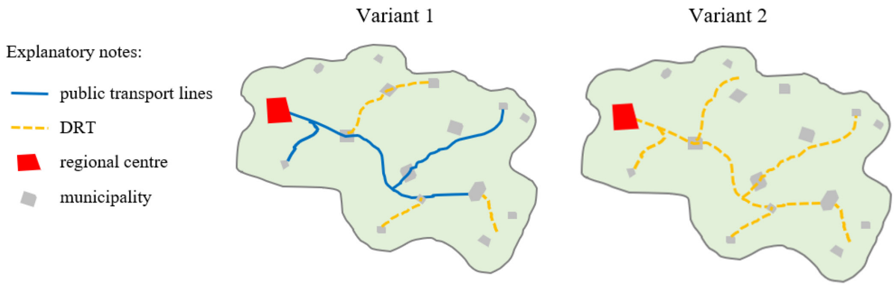

Figure 2 Diagram of Variant 1 and Variant 2

Source: author

Variant 1 is designed for municipalities with a transport accessibility index in the range $3.76 \leq D_x < 5.75$, i.e., areas with a medium level of transport accessibility. These are areas where public bus services are maintained, but there are partial deficiencies in spatial coverage, timing of services, or accessibility to the regional centre.

The basic principle of this variant is to maintain the backbone public bus lines. The DRT system functions here as a supplementary service, aimed at increasing public transport accessibility in locations and at times where regular bus services are inefficient or insufficient. The operational mode corresponds to a semi-flexible DRT system and is characterized by the following elements:

- fixed transfer points and key stops that must be served,
- flexible routing between these points, adapted to passenger requests (demand),
- time coordination with the schedules of the backbone public bus services (ensuring transfers).

Demand-responsive transport is primarily operated during off-peak periods (midday, evening hours, weekends) or in underutilized sections of the area. Functionally, Variant 1 increases spatial accessibility to public transport, reduces walking distances, improves connections to public transport, and allows for optimization of operational costs by deploying the service only where necessary.

Variant 2 is intended for municipalities with a low level of transport accessibility. These are areas with a D_x index value of less than 3.75, where conventional public bus services do not provide an adequate level of service or their operation is chronically inefficient. These are typically sparsely populated areas with spatially dispersed demand and irregular transport needs. In this variant, the DRT system replaces regular public bus services and becomes the primary means of providing transport services in the area.

This variant employs a fully flexible form of DRT, which is not bound to fixed routes or schedules. The principle of the variant is based on:

- serving the area according to individual passenger requests,
- flexible boarding and alighting locations (stop on demand, or a "door-to-stop" system),
- dynamic planning of routes and departure times,
- combining multiple transport requests into a single trip to minimize travel distance (kilometres travelled).

The primary purpose of this variant is to connect municipalities to regional transfer hubs, from which links to public bus services are ensured. Operating hours are adapted to the needs of residents (e.g., commuting to work, school, or medical facilities). Functionally, Variant 2 increases transport accessibility in areas with the lowest D_x values, eliminates inefficient operation of public bus lines, and ensures passenger transport even in areas at risk of social isolation.

The proposed model was subsequently verified in a selected sparsely populated area in the central part of the Šumava region in the Czech Republic. Variant 1, i.e., a combination of the conventional transport service model and demand-responsive transport, proved to be the most suitable for the studied area.

5 Benefits of a dissertation

The main outcome of the dissertation is the design of a mathematical–graphical model for transport services in sparsely populated areas. The proposed model enables:

- evaluating the transport accessibility (particularly by public transport) of the studied area,
- identifying transport-disadvantaged parts of the territory,

- proposing measures to improve transport services,
- simulating different variants of transport service organization,
- selecting suitable vehicles for public bus transport,
- providing a basis for planning and organizing transport services in sparsely populated areas.

The proposed model represents a methodological tool that can be used in decision-making by Regional Transport and Road Management Departments, specifically the Transport Services Sections, as well as by municipal transport departments. Additionally, the model can be employed by transport organizers. An advantage of the model is its relative universality, as it can be applied to other areas with similar socio-economic and geographic characteristics.

The results can serve as a basis for further research focused on the development of integrated and flexible transport service systems in sparsely populated areas. Further research could focus on integrating shared transport into the transport service system, refining and adjusting the model based on data on residents' mobility, evaluating the economic efficiency of different transport service organization variants.

Literature

(1) *Vymezení venkova.* Online. Český statistický úřad. 2007. Available from: Varianty vymezení VENKOVA a jejich zobrazení ve statistických ukazatelích - 2000 - 2006 | Produkty. [cit. 2024-10-26].

(2) LITMAN, Todd. Evaluating Accessibility for Transport Planning. Online. Victoria Transport Policy Institute. 2023, Available from: https://www.vtpi.org/access.pdf. [cit. 2024-10-25].

(3) Nařízení Evropského parlamentu a Rady (ES) č. 1370/2007 ze dne 23. října 2007 o veřejných službách v přepravě cestujících po železnici a silnici a o zrušení nařízení Rady (EHS) č. 1191/69 a č. 1107/70. 2007. Available from: EUR-Lex - 32007R1370 - EN - EUR-Lex (europa.eu).

(4) HANSSON, Joel et al. Replacing regional bus services with rail: Changes in rural public transport patronage in and around villages. Online. *Transport Policy*. 2021, 101, č. 1, s. 89-99. Available from: https://doi.org/10.1016/j.tranpol.2020.12.002. [cit. 2023-12-04].

(5) SZYMANSKA, Elzbieta a KOLOSZKO-CHOMENTOWSKA, Zofia. Sustainable Innovative Mobility Solutions Preferred by Inhabitants of Rural Areas—The Case of Lithuania and Poland. Online. *Sustainability*. 2022, roč. 14, č. 11, s. 6603. Dostupné z: https://doi.org/10.3390/su14116603. [cit. 2024-10-28].

(6) SZÉKELY, Vladimír a NOVOTNÝ, Ján. Public transport-disadvantaged rural areas in relation to daily accessibility of regional centre: Case study from Slovakia. Online. *Journal of Rural Studies.* 2022, roč. 92, č. 1, s. 1-16. Dostupné z: https://doi.org/10.1016/j.jrurstud.2022.03.015. [cit. 2024-10-10].

(7) KÖNIG, Alexandra a GRIPPENKOVEN, Jan. The actual demand behind demand-responsive transport: Assessing behavioral intention to use DRT systems in two rural areas in Germany. Online. *Case Studies on Transport Policy.* 2020, roč. 8, č. 3, s. 954-962. Dostupné z: https://doi.org/10.1016/j.cstp.2020.04.011. [cit. 2024-10-10].

(8) THAO, Vu Thi, Sebastian IMHOF a Widar VON ARX. Integration of ridesharing with public transport in rural Switzerland: Practice and outcomes. *Transportation Research Interdisciplinary Perspectives* [online]. 2021, 10(1), 100340 [cit. 2024-11-19]. Dostupné z: https://doi.org/10.1016/j.trip.2021.100340.

(9) SODER, Michael a PEER, Stefanie. The potential role of employers in promoting sustainable mobility in rural areas: Evidence from Eastern Austria. Online. *International Journal of Sustainable Transportation.* 2017, roč. 12, č. 7, s. 541-551. Dostupné z: https://doi.org/10.1080/15568318.2017.1402974. [cit. 2024-10-28].

Publication activities

KLEPRLÍK, J. – HEŘMÁNKOVÁ, A.: Návrhy řešení parkování v obytných městských částech. Perner´s Contacts, 2020, vol. 15, no. 2, s. 1-12. ISSN: 1801-674X. (J_{OST})

HEŘMÁNKOVÁ, A.: Návrhy řešení organizace turistické dopravy ve vybrané oblasti. Perner´s Contacts, 2022, vol. 17, no. 1, s. 1-10. ISSN: 1801-674X. (J_{OST})

BARAN, F. – HEŘMÁNKOVÁ, A.: The importance of interchange terminals between public transport subsystems on the outskirts of city: case study Pardubice. Transport Means 2023. Part II: proceedings of the 27th International Scientific Conference, 2023, s. 302-308. ISSN: 1822-296X. (J_{SC})

NACHTIGALL, P.; KRBÁLKOVÁ, M.; ČÁP, J.; HEŘMÁNKOVÁ, A.; VOJTEK, M.: Transport accessibility of regional centres as a tool for sustainable mobility. Transportation Research Procedia, 2023, s. 85-93. ISSN: 2352-145. (J_{SC})

HEŘMÁNKOVÁ, A. – KUČERA, P.: The importance of rail transport for transport services in peripheral areas, LOGI – Scientific Journal on Transport and Logistics, 2024, vol. 15, no. 1, s. 13-24. ISSN: 2336-3037. (J_{SC})

HEŘMÁNKOVÁ, A. – KLEPRLÍK, J.: Issues of providing transport services to sparsely populated areas: case study the territory of the National park Šumava in the Czech Republic. Transport Problems. 2024. ISSN: 2300-861X. (J_{SC})

KUČERA, P. – HEŘMÁNKOVÁ, A.: The Use of Automation in Rail Transport to Ensure Interchanges in Regional Passenger Transport. Communications - Scientific Letters of the University of Zilina. 2024. ISSN: 1335-4205. (J_{SC})

HEŘMÁNKOVÁ, A. – KLEPRLÍK, J.: Selection of suitable buses for public bus services in sparsely populated areas using multi-criteria decision-making methods. Transport Means 2025: Proceedings of the 29th International Scientific Conference, 2025, s. 607-612. ISSN: 1822-296X. (J_{SC})

HEŘMÁNKOVÁ, A. – KLEPRLÍK, J.: Use of Demand-Responsive Transport Systems to Ensure Transport Accessibility in Rural Areas. Submitted to journal Rural Sustainability Research. 2026. (J_{SC})

Abstract

The doctoral thesis focuses on the issue of transport services in sparsely populated areas. In the first part, the author analyses the transport services of sparsely populated areas in selected European countries and in the Czech Republic. The second part defines the aim of the dissertation. The third part of the thesis presents the methods used in the research. The main part of the thesis is the fourth chapter, which contains the proposal of a mathematical and graphical model of transport services in sparsely populated areas. The proposal is then verified in the last part of thesis on a selected area in the Czech Republic - Šumava. Finally, the contributions of the dissertation are presented.