

**THESES OF DOCTORAL (PhD)
DISSERTATION**

**ATTILA ERDEI
GÖDÖLLŐ
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**HUNGARIAN UNIVERSITY OF AGRICULTURE
AND LIFE SCIENCES**

**THE TERRITORIAL EFFECTS OF
PUBLIC TRANSPORTATION IN THE
EAST AGGLOMERATION OF
BUDAPEST**

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DISSERTATION**

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1. BACKGROUND AND AIM OF DISSERTATION

1.1. Relevance of the topic

The main function of public transport systems is mobility. Humankind soon saw the spiritual value of transport, beyond the admiration of technology and power. The opportunity for mobility has affected human communities in countless ways. It is a way to ensure competitiveness, a good quality of life and cohesion for society. The main stakeholders in transport systems are passengers, service providers and the organisations with a decision-making and regulatory role (e.g. state, local authorities, public authorities).

One of the inventions of the industrial revolution in the 19th century was the railway, which perhaps had the greatest impact on everyday life and was the most effective stimulus to the industrial revolution itself, the national economy. The railways greatly extended people's freedom of movement, opened up new horizons and connected areas that had hitherto been separated. The main lines of the Hungarian railway network started to be built from the second half of the 19th century. Rail transport in Hungary, which has a history of almost 180 years, is currently carried at a density above the European average. The early 20th century can be described as the 'golden age' of rail transport. Since then, transport needs have increased both in terms of quality and quantity, and these changed circumstances require the development of the Hungarian railways in directions different from those of previous decades.

Budapest and its agglomeration is a major rail hub, both in Europe and nationally, with several European rail corridors running through it, and significant suburban traffic generated by commuters from the suburbs. The development of the Budapest agglomeration is the result of a long process with important historical, urban development and urbanisation aspects. The eastern agglomeration of Budapest is, and has been in the past, densely served by railways and local trains. Both for modern, comfortable, long-distance and suburban passenger transport and for freight transport, rail transport is of major importance and in recent years has been experiencing a 'rail renaissance'.

The transport system is one of the most important infrastructures of settlements, so its condition, location and development are crucial for the future of the regions. The impact of transport infrastructure on spatial development varies. Infrastructure plays a decisive role in the development and transformation of the country and its regions, municipalities, groups of municipalities and the settlement system. This decisive role applies primarily to network infrastructure and is exercised in different ways. The development of transport infrastructure not only dynamically transforms and develops the spatial structure, but also triggers processes of differentiation within it.

Hungary's most important economic, social, cultural and administrative centre is Budapest and its suburbs, home to around a third of the country's population. The development of the suburban and major railway network from Budapest has played a decisive role in the agglomeration around the capital.

The rail and HÉV lines located in the agglomeration continue to play an important role in serving travel needs. Around 1.2 million people cross the borders of Budapest in both directions every day. Of these, 202,000 passengers travel on the main railway lines, 47,000 on the HÉV lines, 198,000 on intercity buses and 755,000 by car. Today's transport demand is on a scale that cannot be met by a network of lines that is in a dilapidated state and designed to meet the needs of the last century. The need for infrastructure development on a scale that can meet these needs justifies an analysis of the impact of rail transport on the Budapest conurbation.

The relevance of the research is that in Hungary today, the infrastructure of local and suburban rail transport is unfortunately plagued with several problems. The current situation in Hungary is generally characterised by the fact that the railways and suburban trains serve isolated areas and that rail transport plays a minimal role in urban transport. Interoperability between rail modes is not ensured. Interconnections are available, but passenger transfer points are not well designed. The structure and density of the national rail network is good (even by European standards), but the main problem is that the national and suburban rail system through Budapest is less and less able to cope with the economic and demographic changes and challenges of recent years. Unfortunately, there is currently no technically and organisationally complex, integrated system that would make the various (national, regional, conurbation and local) transport systems into a coherent and interoperable whole. In order to optimise transport systems at international and national level, it is necessary, on the one hand, to link up the rail, road, etc. networks coming into the region effectively and, on the other hand, to link them properly to regional and local networks.

The basic transport infrastructure of Central Hungary is a network of rail, HÉV, metro, bus lines and main roads connecting urban areas, providing various regional connections. Unfortunately, the development of the fixed rail network in Budapest and its agglomerations has not followed the changes in the settlement structure of the past decades. The network connections of the suburban railway lines have not been implemented, so that the railways still appear as an isolated 'island' in the capital instead of being seen as an option for commuters and city users alike.

1.2. Objectives

The main objective of my research is to investigate the relationship between economic and social changes in recent years and the development of railway infrastructure in the eastern agglomeration of Budapest. The basic idea of my research was the large-scale renovation of the Rákos–Gödöllő–Hatvan (80a) line, which is part of the Helsinki Corridor V, which started at the beginning of my doctoral studies and which, in my opinion, has a significant influence on the economic and social processes in the agglomeration area under study and their future development.

My objective is to examine the impact of the fixed-rail transport systems on the development of the eastern agglomeration of Budapest. In my analysis, I will review the impact of the operation of the Budapest–Gödöllő HÉV line and the Budapest–Hatvan main railway line.

The main aims of my thesis can be summarised in the following points:

The first objective of my research is to define the infrastructural background of public transport by rail.

My second objective is to analyse the economic and social impacts of the changing regional transport network in the eastern agglomeration of Budapest.

My hypotheses are the following:

H1: In the eastern sector of the Budapest agglomeration, the social and economic impact of the linear infrastructure of rail transport on the residents and workers is stronger than that of the HÉV.

H2: In the eastern sector of the Budapest conurbation, the impact of the line infrastructure on economic operators is only indirect and not directly significant.

H3: There is a demonstrable correlation between the development of linear infrastructure (railways) and economic and social processes in the area under study.

H4: In the eastern part of the Budapest agglomeration, it is scientifically proven that the design and accessibility of public transport for different groups of passengers (commuters, students) has a real and demonstrable impact on their daily lives.

H5: The renovation and upgrading of the MÁV and HÉV railway lines serving the eastern part of the Budapest agglomeration will have a positive impact on the residents, businesses, municipalities and local authorities concerned.

2. MATERIAL AND METHODS

I conducted my literature research using the PRISMA model. The PRISMA method of systematic literature review aims to reduce researcher bias in the literature search by identifying and analysing the studies included in the review according to specific procedures.

My independent analyses are based on primary and secondary information. My research topic focuses on the eastern agglomeration of Budapest, so only limited use was made of foreign data. The domestic secondary sources are typically taken from the internal database of MÁV-START Zrt. and from the Spatial Development Monitoring and Evaluation System (T-MER) of the National Spatial Development and Planning Information System (TeIR).

In defining the methodology of scientific research, it is also necessary to decide whether our research objectives can be achieved by qualitative (qualitative) or quantitative (quantitative) methods, or a combination of both. Quantitative research is usually deductive, i.e. we collect information on a large sample to verify our hypotheses and theoretical claims (BABBIE 2008). The main research tools used in my study are, for example, questionnaires (suitable for descriptive, explanatory and exploratory purposes) and structured interviews.

My primary investigation focuses on the settlements of the eastern sector of the Budapest agglomeration, where public transport (H8/H9 HÉV, MÁV 80 main line) is located (Csömör, Gödöllő, Isaszeg, Kerepes, Kistarcsa, Mogyoród, Nagytarcsa, Pécel), where I addressed the following target groups:

- questionnaire survey: special group of passengers (study of the transport habits of secondary school pupils on their way to school and of commuters);
- structured interviews: representatives of the municipalities concerned and larger enterprises (over 50 employees) based in the municipalities.

Both the questionnaire and the structured interviews were conducted face-to-face with the target group, so the information and experience I gained on the ground contributed to the validity of my conclusions and findings. In my primary research, I did not use qualitative techniques (e.g. observation, focus groups, and case studies).

The aim of my sub-study in the Gödöllő district is to assess the school travel preferences of secondary school students, in particular to map in detail their travel habits to school, taking into account the railway line renovation. It is important to note here that the role of a railway line can be particularly examined when it is out of service for some reason (e.g. track renewal). The target group of the sub-study were secondary school students in secondary schools in the municipalities along the 80a railway line under renovation (Gödöllő, Isaszeg, Pécel).

These settlements are both origins and destinations of commuting of pupils, also because of their location. I have chosen this target group (born between 1995 and 2009) for my research because they are the first global generation in the world, they are already ‘consciously travelling’ and most of the students are already commuting for educational purposes. The commuting habits of school pupils, through their families, have an important impact on practically the complete local society, influencing the way they live their daily lives. The target group under study is secondary school pupils in year 11, because during the study period (15 May 2019 to 12 June 2019), year 12 pupils were unavailable due to the school leaving examination period. Year 9 and 10 pupils did not have as much experience of the previous period, which is relevant for some of the items in the questionnaire. My questionnaire survey contained 21 questions.

After the secondary school students, I conducted a structured expert interview with the representatives of the local governments of the settlements located in the eastern part of the Budapest agglomeration, in which I examined the effects of the renovation and modernisation of the HÉV and MÁV railway lines serving the area on the economic and social life of the settlements. The interviews were ‘strung’ around 18 questions. The first part of the interview focused on the transport network of the municipality, its public transport links, its situation, structural changes and the transport links of its urbanisation areas. Then, the factors influencing the social development and demographic conditions of the municipality were reviewed. The interview concluded with an overview of the public transport developments (affecting the municipality) in the last 30 years, the expected impact of their modernisation on the economic and social life of the area, and future public transport development needs and plans.

According to the Ceginformacio.hu database, in August 2021 there are 39 enterprises with more than 50 employees in the surveyed municipalities. All the companies concerned were contacted first by telephone and then by e-mail to request their cooperation. After several contacts, unfortunately ‘only’ 11 of the total number of enterprises participated in the structured expert interview. I was therefore able to work with a small sample compared to the total target population, but my research experience and my understanding was that I was still able to obtain representative results.

The survey of commuter passengers was carried out between 1 and 31 October 2021. Commuter passengers were reached at railway/HÉV stops in the surveyed municipalities of the eastern agglomeration of Budapest. The questionnaire contained 12 questions. When compiling the questionnaire, it was important to ensure that waiting passengers had time to fill in the questionnaire while still at the station.

I also prepared a SWOT analysis to assess the situation of the domestic rail transport sector and to help organise and select the findings. The identification of internal strengths and weaknesses precedes the identification of external conditions, i.e. opportunities and threats, and the two sides need to be aligned. However, not all state characteristics should and should not be listed in the SWOT table, but only those that are relevant and decisive for the analysis (PAPP-VÁRY 2015). According to a study by FARAGÓ (2001), the SWOT analysis combines situation assessment with strategy making in a narrower sense.

Finally, for the municipalities located in the agglomeration of Budapest, I investigated interrelationships based on spatial statistical data using quantitative methods (factor analysis, binary logistic regression). Statistical data on municipalities in Hungary are available (e.g. from census, spatial statistics) and these data can be used to investigate the relationships with economic and social factors. The selection of the statistical data under investigation was based on the methodology accepted in the social sciences (see e.g. RITTER et al. 2013; TÓTH 2017; TÓTH - JÓNA 2019).

Based on the literature, factor analysis is a particularly suitable method for researching problems because it can be used to ‘map’ even large data sets. Factor analysis is a multivariate statistical method for data compression, reducing the number of variables and exploring the data structure. In factor analysis, variables that are characteristic of a municipality can be arranged into groups (factors) in such a way that variables in a group are highly correlated with each other but not with variables outside that group. Logistic regression is a multivariate method for categorising cases according to the categories of the dependent variable. In this case, we check whether, and to what extent, membership of the group can be estimated.

The source of the data I used is the National Spatial Development and Planning Information System (TeIR), including the Spatial Development Monitoring and Evaluation System (T-MER), the Municipal Data Collection System, the System of Spatial Statistical Data (T-STAR), and passenger data from MÁV-START Zrt. and MÁV-HÉV Zrt. The data were statistically analysed using IBM SPSS Statistics for Windows, Version 27 and GeoDa.

3. RESULTS AND DISCUSSION

3.1. Results of the survey among secondary school students

The total number of assessable items received was $n=526$. 41% of respondents were boys (217) and 59% were girls (309).

The student commuting results approximate the 2011 statistics for agglomeration commuting. Among the students surveyed, the share of commuters was close to 70%. The share of commuters living in and commuting from Budapest was 12% of the total population, which is also close to the 2011 statistics on working age commuter rates.

Students typically choose to commute by long-distance/interurban bus (41%) or on foot (19%), which can be considered justified by the proportion of people living locally (Figure 1).

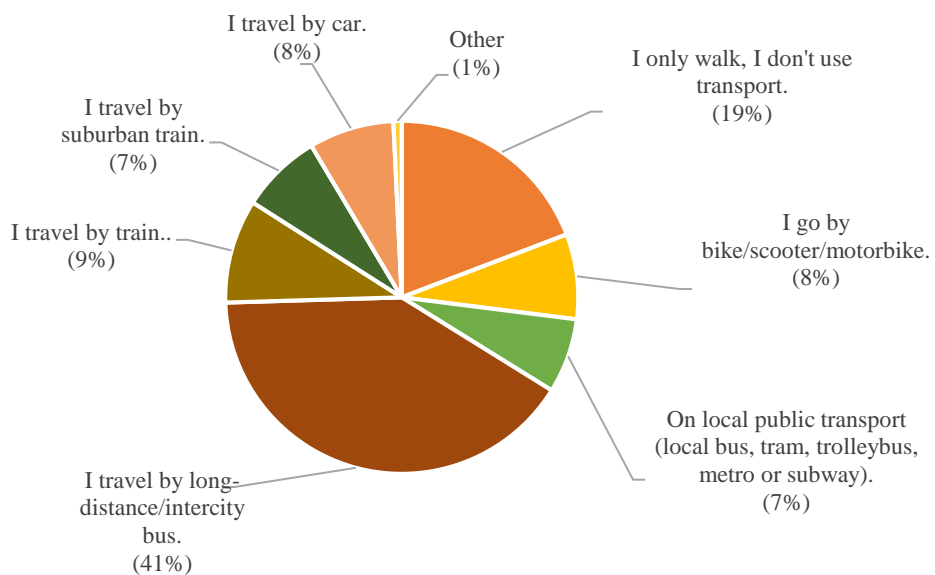


Figure 1: Distribution of respondents' morning school attendance (%) (n=526 persons)

Source: Author's own edition (2022)

The survey also assessed the satisfaction of respondents using public transport. I took into account the responses of students who used public transport to get to school in the morning (train, metro, long-distance/local bus, local transport). In this case, the number of items included in the analysis was 339 ($n_{kk}=339$ persons).

The current level of service quality has been shaped by funding constraints in recent decades. The most difficult to improve is the quality of infrastructure elements (e.g. stations, railway stations), given their very high cost. Students were most dissatisfied with congestion, reliability, cleanliness of stops and vehicles (Figure 2).

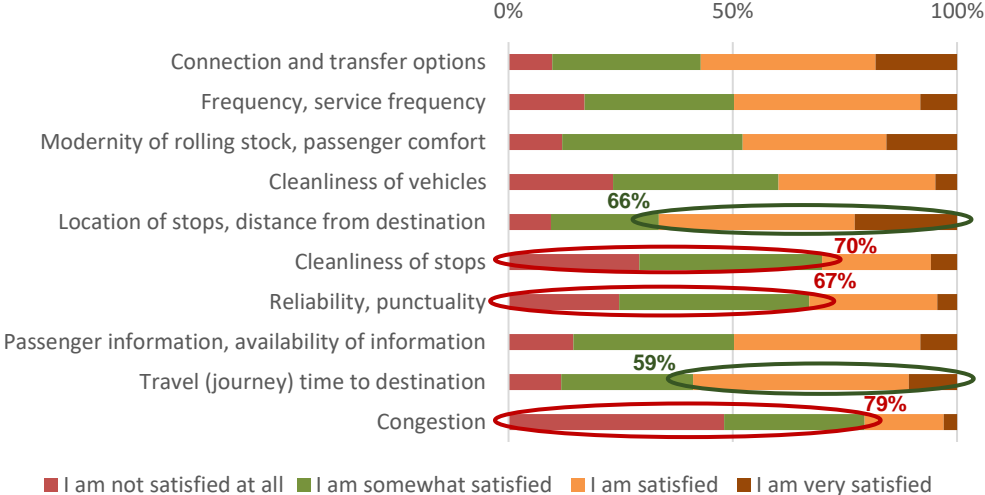


Figure 2: Satisfaction of secondary school students using public transport with the service used (%) (n_{kk}=339 persons, n=526 pieces)

Source: Author’s own edition (2022)

A particularly prominent negative opinion is the crowding factor, where I scored close to 80% in the two lower categories (not at all satisfied, somewhat satisfied). Students are most satisfied with the location of stops, travel (journey) times and connections. The highest overall score in the top two categories (satisfied, very satisfied) was found for the indicator ‘location of stops’. For passenger information, comfort of vehicles and frequency of service, the positive and negative opinions are about equally balanced.

I then further narrowed down the number of items analysed by looking at the opinions of pupils who use public transport (rail, HÉV) to get to school in the morning. The resulting number of elements was 89 (n_{vh}=89 persons).

The two lower categories (not at all satisfied, somewhat satisfied) were close to 70% for the cleanliness of stops and vehicles. Students using fixed rail transport were most satisfied with the location of stops, journey (travel) times, frequency and connections. Positive and negative opinions are about equally high for the comfort and reliability/ punctuality of vehicles.

3.2. Results of the structured interview survey of municipalities

I conducted a structured expert interview with local government representatives of the settlements in the eastern part of the Budapest agglomeration, in which I examined the effects of the renovation and modernisation of the HÉV and MÁV railway lines serving the area on the economic and social life of the settlements. The 5 municipalities interviewed all belong to the district of Gödöllő and have a fixed public transport system like railways, suburban railways (HÉV). Rail transport is available in the municipalities of Gödöllő, Isaszeg and Pécel, while the HÉV (suburban railway) serves the municipalities of Gödöllő, Mogyoród and Csömör.

The local and interurban public transport connections in the municipalities, according to the opinion of the representatives of the municipalities, do not provide a homogeneous picture. Some municipalities, such as Gödöllő, Pécel, Isaszeg, have good or excellent public transport connections. The public transport system of these municipalities is characterised by the fact that several modes of transport (rail, HÉV, bus in the case of Gödöllő, while rail and bus in the case of Pécel and Isaszeg) provide a suitable transport option for commuters to school and work.

In contrast, Mogyoród and Csömör would need significant improvements in public transport. In both cases, the representatives of the municipality considered it important to increase the frequency of services to meet demand and to have a regular and predictable timetable to attract passengers to public transport.

Respondents were divided on local transport connections in urbanisation areas. In some municipalities, public transport services are being continuously upgraded to serve new housing estates, industrial estates and shopping centres. In many cases, the economic potential of municipalities is limited and they are unable to finance the extension of services or the introduction of new services.

The development of the Budapest-Gödöllő-Hatvan railway line will have an impact on the life of the municipalities concerned and it is expected that more people will switch to rail transport as a result of this development. Three of the five municipalities studied are located along the railway line, and naturally the impact of the railway development on the life of the municipalities was/is much greater, as the negative and positive effects of the investment are more concrete.

The interviewees said that the accessibility of their settlements has been improved by the upgrading, and that residents have been very patient with the inconvenience of the train replacement during the upgrading, and are all looking forward to the punctual and modern rail service on the upgraded line.

The HÉV, as a traditional mode of transport, is part of the eastern agglomeration of Budapest, but has not yet been developed. In Gödöllő, both the railway station and the HÉV stops are close to the city centre and therefore easily accessible. In each of the three municipalities affected by the HÉV, the people concerned are eagerly awaiting the reconstruction of the line, as it is not possible to provide a 21st century public transport service with 50-year-old vehicles and dilapidated service facilities.

A weakness of the transport infrastructure in the study area is that between the outer districts of Budapest and the agglomeration, the transport infrastructure is radial, so there are no diagonal and circular transport options.

Transport service facilities (e.g. stops) in the study settlements are currently in a typically poor condition. The interviewees agreed that the HÉVs in Gödöllő and Csömör need to be completely renovated, the tracks need to be cleaned up, speed restrictions need to be removed and the platforms need to be made accessible.

The majority of the municipalities surveyed have problems in dealing with the heavy traffic in the morning and afternoon. In all municipalities, traffic peaks occur between 7-8 am and 5-6 pm, with daytime passenger traffic being spread out. Therefore, it would be important to improve the quality of public transport to provide an attractive alternative for car users.

3.3. Questionnaire survey of commuting passengers

I also carried out a questionnaire survey among commuter passengers along the rail and HÉV lines. The total number of questionnaires evaluated was 221. Unfortunately, due to the risk of epidemic in Covid-19, the response rate was low. 40% of the respondents (88) were male and 60% (133) were female. The age of the respondents showed that the youngest respondent was 16 and the oldest 68. 54% of respondents were under 40 years old and 22% were over 51 years old.

Among the travellers surveyed (n=221), commuting for work or study accounted for nearly 60%, with shopping and leisure also being important factors, with 18% and 15% respectively (Figure 3).

The responses to the questionnaires show that nearly 50% of respondents use public transport, the most frequent being railways (19%), urban transport (16%) and intercity buses (14%). However, the use of private transport, such as cars, motorcycles, scooters and motor scooters, is also significantly significant. Among these means of transport, the use of cars is the most common commuting mode among respondents.

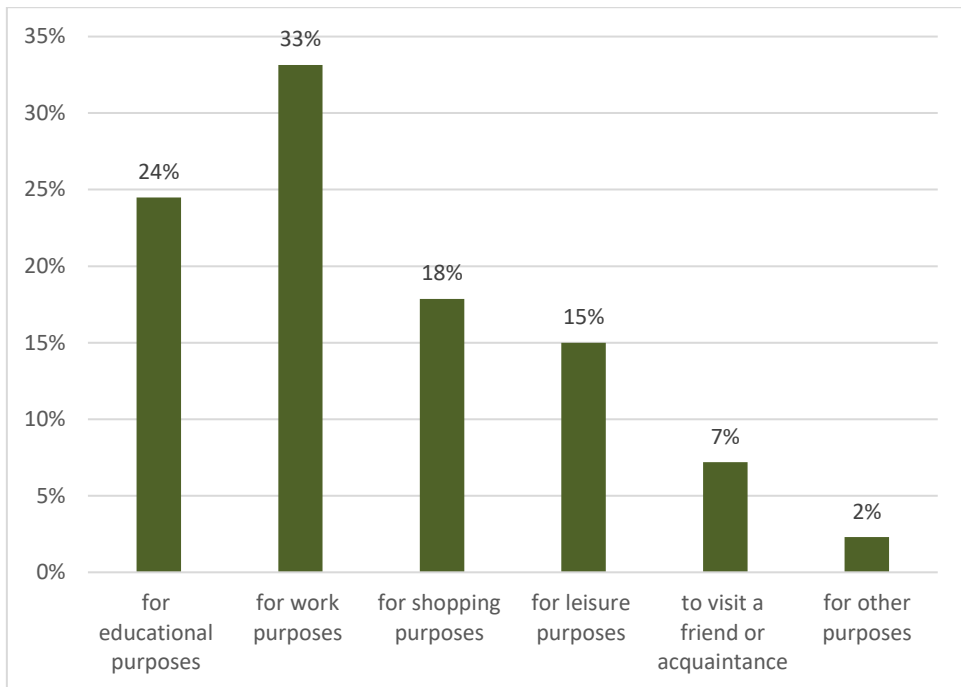


Figure 3: Percentage of respondents who commute between Budapest and the surrounding area (%) (n=221 persons, n_v=347)

Note: more than one answer was possible

Source: Author's own edition (2022)

The evaluated questionnaires show that passengers were most dissatisfied with the crowding, reliability and cleanliness of stops. A particularly prominent negative opinion is the crowding factor, with a total score of 51% in the two lower categories (not at all satisfied, somewhat dissatisfied).

Passengers were most satisfied with the modernity of the vehicles, passenger comfort and frequency and frequency of services. As seen in the previous sub-chapter, both rail and HÉV run at 15-30 minute frequencies during the day on weekdays, which leads to passenger satisfaction.

The highest satisfaction scores in the aggregation of the two top categories (satisfied, very satisfied) were found for the indicator 'modernity of vehicles, passenger comfort'. For several indicators (location of stops, passenger information, journey times), it was observed that the middle category (neutral) received the highest number of responses.

3.4. Results of company investigations

Most of the companies surveyed are in the manufacturing or services sector. Their main activity is the production of various sub-assemblies and the manufacture of chemical and pharmaceutical products.

All enterprises had more than 50 employees on 31 December 2020. I have chosen firms with more than 50 employees because, firstly, they have a higher economic strength, secondly, they have a higher commuting of employees (which is compensated by costs, e.g. inter-local rent) and, thirdly, they have a higher demand for transport infrastructure related to their activity.

Overall, according to the surveyed enterprises, only a small percentage of employees use public transport for their daily commuting to work. Workers typically use private cars and, to a lesser extent, local buses. Business premises are located more than 2-3 km from fixed rail transport stops (rail, HÉV), making it difficult for workers to get around.

Rail is a reliable mode of transport and is not polluting, but the companies surveyed have no direct rail transport links at all and no factory siding. It is also important to add that there is no need for siding in the near future in relation to their activities.

The rail transport sector is not attractive enough for the enterprises surveyed, and they do not use rail transport directly in their activities. Rail operators are not able to guarantee the reliability and timeliness required by businesses, so they use other modes of transport, typically road transport.

The representatives of the companies interviewed did not mention proximity to the railways as an important factor in their choice of location. Unfortunately, the decline in the volume of rail transport is also a tangible phenomenon here, with interviewees stating that rail transport is not a decisive factor for their companies.

3.5. SWOT analysis of rail transport

I have carried out a SWOT analysis to explore the situation of rail transport and identify possible development directions. The main findings of the SWOT analysis based on the secondary literature and my primary research are presented in Table 1.

The main strengths of HÉV are its reliability and predictability, the favourable geographical location of its lines, its strong market image and its environmental friendliness. Weaknesses include an outdated technical infrastructure (track), a lack of accessibility and little influence on tariff policy.

Table 1: SWOT analysis of fixed rail transport in (2022)

Strengths	R*	Weaknesses	R*
– Low emissions and specific energy consumption	5x5	– Old, slowly changing, low energy-efficient and polluting vehicle fleet	-4x5
– More favourable modal split than the EU average (overall share of private motorised transport lower than the EU average)	5x5	– Centralised layout, Budapest centricity	-4x4
– Social and political support at national and European level	4x5	– Decades of deterioration of some infrastructure elements	-4x4
– Strong national economic importance	4x5	– Difficult to manage incidents and accidents	-4x3
– Favourable economic geography	5x4	– Coordination of spatial and urban development, environmental protection and transport development is sometimes difficult	-4x3
– Basic transport infrastructure in place	4x4	– Significant regional disparities in accessibility	-3x4
– High-capacity vehicles that are considered new for 10-12 years and have a long service life	4x4	– Low degree of multimodality and interoperability	-3x3
– Existing cross-border transport management potential and operational cross-border models and lines	4x4	– Shortcomings in road communication	-3x3
– Scalable vehicle size for fluctuations in demand	3x3	– Declining road safety, passenger safety and accident rates	-3x3
Opportunities	R*	Threats	R*
– Main lines well integrated into the international core network (TEN-T)	4x4	– Energy dependence and extreme increase in fuel prices	-5x5
– EU support for a liveable environment and sustainability	4x4	– Labour shortages in transport	-5x5
– Development of intermodality	4x3	– The continued rise of private transport	-4x5
– Improving the competitiveness of public transport in order to maintain and increase its share	3x4	– Low level of development funding	-4x4
– Positive change of mindset to further increase the share of urban transport (especially Budapest)	3x4	– Poorly prepared liberalisation process causing market loss	-3x4
– Exploiting the benefits of market opening	3x3	– Negative social perception	-3x4
– Increased European integration	3x3	– Unfavourable timetable concept leads to a decrease in passenger numbers	-3x3
		– Macro-regional transport arteries bypass the country	-3x3
		– Competition between regions and modes of transport due to limited resources	-3x3

*: Rank = intensity x importance (max. 5x5)

Source: Author’s own edition (2022)

Opportunities could be seen in exploiting the cooperation resulting from the membership of the MÁV group, joining the National Electronic Ticketing Platform and developing the direct north-south non-stop connection of the HÉV network. Threats should be considered in the light of the growing importance of private transport, the constantly changing legal framework and the instability of public support for development.

3.6. Statistical analysis of municipalities and public transport in the Budapest agglomeration

I have carried out detailed studies on the statistical analysis of public transport in the Budapest agglomeration and on public transport by rail. The study sample included the municipalities of the Budapest agglomeration ring where public transport is available.

Firstly, I analysed whether the situation of the settlements could be used to predict the renewal of the lines after 2008, i.e. whether there is any statistically detectable correlation between the situation of the settlements and the occurrence of the renewal. I chose the year 2008 because, on the one hand, the 10-12 year old track is still almost new in terms of railway infrastructure. So, that 2008 can be considered as the 'frontier' at the time of my research, and on the other hand, it is the first year in which the renewal of the fixed rail network appeared significantly in the region under study.

I originally included more than this, a large number of municipality-level variables from the databases described in the 'Material and Methods' section. The variables and the indicators derived from them were designed to include as many characteristics of the municipalities as possible that could be used for the situation analysis. Variables with low weight (explanatory power), as determined by statistical analysis software or factor analysis, were omitted.

After the factor analysis, the correlation analysis was performed using binary logistic regression with the dependent variable being the binary variable (*feluj_2008*) recording the fact of track renewal after 2008, with a value of 1 if renewal occurred; 0 if no renewal occurred after 2008. The logistic regression method was chosen because, in addition to the factors, non-metric explanatory variables (e.g. sector code, type of vehicle) were also tested in the analysis before setting up the final model. These variables could not be tested using discriminant analysis.

Prior to the analysis, I examined my indicators formed from the baseline data for the applicability of factor analysis. Based on the MSA measures of the settlement characteristic variables, I excluded from the analysis a number of original indicators that I had formed from the baseline data.

The MSA of the remaining indicators ranges from 0.485 to 0.866. Their average, the KMO measure (for all variables simultaneously), is medium, with a value of 0.667, which confirmed the suitability of the data for factor analysis. The Bartlett chi-square test is a function of whether the correlations between variables are significantly different from zero overall. The significant result of the Bartlett's test ($\chi^2=426.786$, $df=66$, $sig.<0.001$) confirmed the adequacy of the correlation structure.

In the analysis, four factors were created. The number of factors was determined using the Kaiser criterion, which recommends to keep all factors with eigenvalue of at least 1. The same number of factors was obtained using the variance-ratio method, which suggests to keep as many factors as can retain at least 60% of the total variance. The four factors included in the study can retain 67.177% of the total variance.

The 4 factors constructed are shown in Table 2.

Table 2: Factor structure of characteristics of settlements (2008)

	Factor (FAC)			
	1	2	3	4
Proportion of high and low income earners (persons)	0,930			
Net income per capita (HUF)	0,915			
Number of registered enterprises per thousand inhabitants (number)	0,805			
Ageing index (%)		0,809		
Deaths per thousand inhabitants (persons)		0,640		
Live births per thousand inhabitants (persons)		-0,601		
Migration balance (thousands)		-0,470		
Registered non-profit and other non-profit institutions per thousand inhabitants (number)			0,725	
Number of cultural events per thousand inhabitants (number)			0,714	
Permanent population (persons)			-0,632	
Number of libraries per 100 inhabitants (number)				0,735
Percentage of permanent population aged 18-59 (%)				0,686

Source: Author's own edition (2022)

After performing the factor analysis, I tried to identify the resulting factors on the basis of the variables sorted into a factor. Thus, I formed the following groups of characteristics:

- FAC1₂₀₀₈: economic situation
- FAC2₂₀₀₈: social erosion
- FAC3₂₀₀₈: community cohesion (small town character)
- FAC4₂₀₀₈: active community culture

In the next step, using the FAC1₂₀₀₈-FAC4₂₀₀₈ factors as independent variables and renovation (feluj₂₀₀₈) as dependent variable, I constructed a binary logistic regression model to estimate the effect of the FAC1₂₀₀₈-FAC4₂₀₀₈ settlement characteristic factors on the probability of renovation. I constructed the model using a forward (Wald) variable selection method.

The resulting regression model can be written as:

$$\text{logit} = -1,655 - 1,426 \cdot \text{FAC3}_{2008} \quad (1)$$

thus, only FAC3_{2008} (Wald=7,077, df=1, sig.=0,008), and constant (Wald=21,721, df=1, sig. <0,001) were significant among the explanatory variables.

An increase in the FAC3_{2008} factor score (i.e. the community cohesion factor score) was associated with a decrease in the odds of renewal (a one unit increase in $\exp(-1.426)=0.240$ times less likely to renew). Two of the three indicators in the FAC3_{2008} factor have a positive sign and one has a negative sign. Their effect is proportional to their sign, i.e. for those with a positive sign, an increase in the indicator does indeed imply a lower probability of renewal. However, for the indicator with a negative sign (Permanent population), an increase in absolute value implies an increase in the probability of renewal. In simple terms, we can say that the three indicators of the FAC3_{2008} factor value have two effects. A change in the two indicators with positive signs has the opposite effect to a change in the indicator for the probability of renewal, i.e. an increase in the two indicators leads to a decrease in the indicator for the probability of renewal. In the case of the indicator with the negative sign 'permanent population', an increase in the indicator implies an increase in the renewal indicator.

My analysis aimed to explore which factors are good predictors of development. Thus, from the above analysis, it can be concluded that the municipality characteristic factor FAC3_{2008} , constructed from the following indicators:

- the number of registered non-profit and other not-for-profit organisations per thousand inhabitants,
- the number of cultural events, and
- the permanent population

had a significant effect on the likelihood of renovation. Increases in the number of registered non-profit and other not-for-profit organisations and the number of cultural events were associated with a decrease in the probability of renovation, while an increase in the permanent population was associated with a higher probability of renovation.

Thus, based on my analysis, it is partly plausible that there is a positive correlation between the renovation of public transport infrastructure and the permanent population indicator, while the small-scale nature of the population is a factor that tends to work against renovation.

In the second step, I examined the municipalities using the latest available data for 2019 to see if there is a correlation between rail renovation and socio-economic indicators in the opposite direction.

In this analysis, I have created five factors, where the number of factors is determined by the Kaiser criterion (Table 3).

Table 3: Factor structure of the characteristics of the municipalities (2019)

	Component				
	1	2	3	4	5
Percentage of the permanent population aged 60-X (%)	,950				
Ageing index	,870				
Percentage of the permanent population aged 18-59 (%)	-,853				
Natural increase/decrease (thousands)	-,822				
Net income per capita (HUF)		-,819			
Unemployment rate		,801			
In the case of time optimisation, the fastest trip in minutes to Budapest		,725			
Cultural events (per thousand inhabitants)			,767		
Registered non-profit and other non-profit organisations (per 1000 inhabitants)			,705		
Number of libraries per 100 inhabitants (number)			,552		
Persistent unemployment rate (%)				,876	
Number of registered businesses per thousand inhabitants (number)				,592	
Number of general practitioners per 1000 inhabitants (with general paediatricians)					,868
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.					

Source: Author's own edition (2022)

The dimensionality reduction also does not require an interpretation of the factors, but after performing the factor analysis, I have given a possible interpretation of the resulting factors based on the variables that are ordered into a factor. Thus, the following groups of characteristics were formed:

- FAC1₂₀₁₉: ageing
- FAC2₂₀₁₉: peripherality
- FAC3₂₀₁₉: active community and culture
- FAC4₂₀₁₉: compulsory employment
- FAC5₂₀₁₉: health

For these, as explanatory variables, I performed binary logistic regression calculations. The dependent variable is whether there has been a railway renewal since 2008.

I constructed a binary logistic regression model to estimate the effect of the settlement characteristics factors FAC1₂₀₁₉-FAC5₂₀₁₉ on the probability of renovation. Again, I constructed the model using the forward (Wald) variable selection method.

The resulting regression model can be written as:

$$\text{logit} = -1,200 - 0,875 \cdot \text{FAC2}_{2019} \tag{2}$$

thus, only FAC2₂₀₁₉ (Wald=7,207, df=1, sig.=0,007), and constant (Wald=16,853, df=1, sig. <0,001) were significant among the explanatory variables (Figure 4).

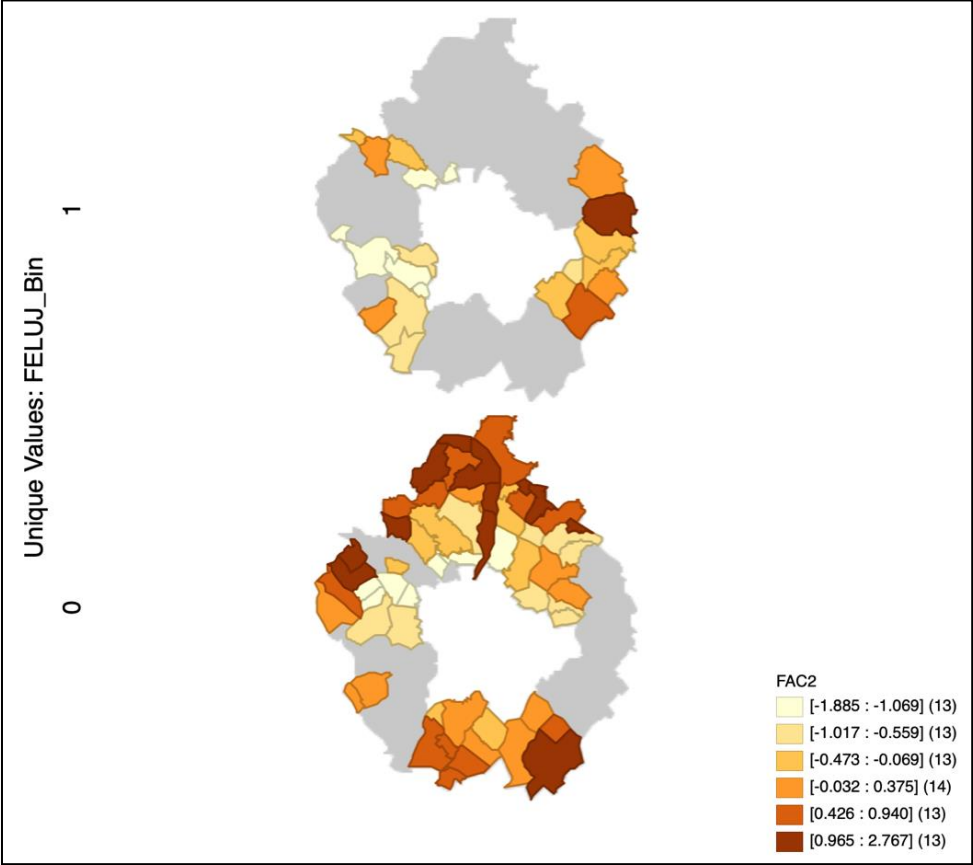


Figure 4: The correlation between FAC2₂₀₁₉ and renovation in the agglomeration of Budapest (2019) (0: no, 1: yes)

Source: Author’s own edition (2022)

Two of the three indicators in the $FAC2_{2019}$ factor have a positive sign and one has a negative sign. Their effect is proportional to their sign, i.e. for those with a positive sign (unemployment rate and the fastest trip length in minutes to Budapest for the time optimisation), an increase in the indicator does indeed imply a lower probability of renewal. However, for the indicator with a negative sign (Income per capita), an increase in absolute value implies an increase in the probability of renewal.

The aim of my analysis was to explore which factors are good predictors of upgrading that has already taken place. Thus, from the above analysis, it can be concluded that the municipality characteristic factor $FAC2_{2019}$, constructed from the following indicators:

- Income per capita (HUF)
- Unemployment rate (%)
- The fastest trip length in minutes to Budapest for the time optimisation (minute)

significantly associated with the presence of renovation. Increases in the unemployment rate and the fastest trip in minutes to Budapest indicators are typically associated with decreasing chances of renovation.

At the same time, an increase in net income per capita is associated with a higher probability of renovation taking place. Thus, peripherality and economic development are associated with improvements in linear infrastructure.

On the basis of my analysis, it is therefore plausible that there is a demonstrable correlation between the development of linear infrastructure (railways) in the study area (when it has taken place) and economic and social development.

4. CONCLUSIONS AND SUGGESTIONS

The result of my thesis is a review of the academic literature on suburban railways using the PRISMA model. It can be concluded that, according to national and international literature, the development of infrastructure, and in particular the development of fixed-rail infrastructure, plays a crucial role in the development of polycentric agglomeration urban groups. The academic publications examined suggest that rapidly changing suburbanisation processes can change the characteristics of transport demand in a given area in a short space of time, whereas transport infrastructure is inflexible, requiring years, often decades, the coordination of the interests of numerous players and changes in the legislative environment to be made to adapt it to needs.

The results of my hypothesis testing are:

T1: Based on my research, I accept my hypothesis that in the eastern sector of the Budapest agglomeration, the impact of the linear infrastructure of the train is stronger than that of the HÉV.

The two important rail transport ‘backbones’ of the transport map of the eastern agglomeration of Budapest are the HÉV line in Gödöllő and the MÁV main line 80a (Budapest-Hatvan), which forms an almost loop with it. The rail transport infrastructure in the eastern area has an important impact on the region. A review of the history of the HÉV reveals evidence of the existence of other lines that have also had a significant impact on the economic and social development of the region.

An analysis of the commuting patterns of 11th grade students living and/or studying in 3 municipalities of the Gödöllő district (Gödöllő, Isaszeg, Pécel) shows that the commuting patterns of students are significantly close to the statistics obtained from the 2011 census. The share of commuters from other municipalities to secondary schools in the three municipalities surveyed is close to 70%. The results of the research show that public transport plays a key role in the lives of students.

Students who use public transport are ‘critical’ about the services they use and their satisfaction is strongly influenced by infrastructure and vehicle improvements. Both public transport users and users of public transport by rail were most dissatisfied with congestion, cleanliness of stops and vehicles, and most satisfied with the location of stops, journey times and connections.

Based on my research, I can conclude that for the municipalities, the HÉV plays a less important role than the railways. The main reason for this is the technically worn-out state of the infrastructure and rolling stock and the resulting passenger dissatisfaction.

Although the number of passengers on the HÉV is significantly higher than on the railways, the majority of HÉV passengers use the line within the administrative boundaries of Budapest.

T2: I accept my second hypothesis, i.e. that in the eastern sector of the Budapest agglomeration the impact of the linear infrastructure is only indirect and of no direct importance for economic actors.

Rail transport, which was still significant in the 1970s and 1980s, declined significantly throughout Hungary after the change of regime. Freight transport on the HÉV network was discontinued and the freight wagons were sold. An examination of the MÁV network map shows that only one siding has survived in the area under study, between Isaszeg and Gödöllő, but even this has a traffic volume close to zero.

For the companies interviewed in the primary survey, the priority given to the emergence of fixed rail transport is not significant. For the companies with a small number of commuters and a small number of employees, rail transport is only present on a few routes (rail/HÉV).

T3: I accept my third hypothesis, i.e. that there is a demonstrable link between the development of linear infrastructure (railways) and economic and social processes in the area under study.

Demographic indicators in the study area have been on the rise in recent years. There has been a significant increase in the size of the population and a high level of migration.

Statistical data show that the proportion of the population of the agglomeration compared to the population of Budapest was only 43% in 1970. This proportion has now increased to 68%. Today, around 270,000 cars enter Budapest from the agglomeration every day. Looking at the queues of cars on the roads, it is clear that this phenomenon cannot be remedied by road improvements alone.

The expected future growth of the agglomeration will generate additional high mobility needs that cannot be met without competitive rail and HÉV connections. Unfortunately, the quantitative increase in linear infrastructure has not been achieved in the last 40 years, but the recent (2018-2021) development of rail lines could have an important impact on the agglomeration area under study.

Statistical analysis (factor analysis and binary logistic regression) of the municipalities and public transport by rail in my study confirmed my hypothesis that there is a positive correlation between the renewal of public transport infrastructure and certain demographic indicators, such that demographic changes require the development of rail infrastructure.

T4: I partially accept my fourth hypothesis that in the eastern part of the Budapest agglomeration it is scientifically proven that for different groups of passengers (commuters, students) the design and accessibility of public transport has a real and demonstrable impact on their daily lives.

The daily commute is a daily activity for people living in agglomerations, which (also) involves the use of public transport. This is a daily repetitive process that affects a significant part of the population. The social and economic processes of agglomeration and public transport infrastructure are closely interlinked. It has a significant, albeit slightly different, impact on different groups of passengers (commuters, students).

Infrastructure development has a complex impact on the daily lives of people living in the region. Commuting is conditional on the proper development of public transport links between settlements. Inter-regional transport systems need to be improved, as in many cases they do not allow for efficient spatial integration. New cooperation in transport management can help to better serve the transport needs within the regions and to ensure efficient and sustainable economic development of the region. It is important to develop territorial coordination in transport within municipalities. My primary research has shown that public transport, in particular public rail transport, has a significant impact on the settlements, communities and people living, working and studying in the eastern sector of the Budapest agglomeration.

T5: I accept my fifth hypothesis, i.e. the renovation and modernisation of the MÁV and HÉV railway lines serving the eastern part of the Budapest agglomeration will have a positive impact on the residents, businesses, municipalities and local authorities concerned.

Daily commuters by car to Budapest represent a heavy traffic on the road network. For those travelling from the region to Budapest, only the development of rail transport can offer an environmentally friendly alternative. Public transport lines (rail, HÉV) need to become competitive with car transport. My primary research shows that the development of the Budapest–Gödöllő–Hatvan (80a) railway line will have a positive impact on the life of the municipalities concerned and that it is expected that more people will switch to rail transport as a result of this development.

In the case of the settlements adjacent to and in the immediate vicinity of the railway line under study, the impact of the railway development on the life of the settlement is naturally much greater. Representatives of the municipalities said that residents have been very patient with the inconvenience of the train replacement during the renovation and are all looking forward to the punctual and modern rail service on the rebuilt line.

Over the past 175 years, the development of rail links in the Budapest agglomeration has significantly increased the proportion of commuters in suburban settlements. An important outcome of this dissertation is to highlight areas where development challenges in the field of public rail transport are emerging.

Based on my research, I propose the following main areas for improvement:

- to decentralise the rail network away from the capital: the development of a railway line bypassing Budapest (mainly serving freight traffic),
- harmonisation of a common timetable between HÉV-railway-Volánbusz,
- Develop a common ticket and fare system between HÉV-railway and Volánbusz, develop electronic ticketing systems,
- meeting the objectives of the Budapest Agglomeration Rail Strategy,
- Promoting the coordination of regional, urban and transport infrastructure development, reinterpretation of urban feeder networks,
- Complete reconstruction of the HÉV (e.g. replacement and upgrading of rolling stock, possible track correction)
- passenger information, management of stops, vehicle cleanliness and congestion for commuters and school users using public transport,
- stakeholder involvement: intensifying dialogue with local authorities, residents and businesses.

5. NEW SCIENTIFIC RESULTS

- 1. My research has confirmed that the development of fixed rail infrastructure has a significant, but differentiated, impact on different social groups (commuters, students, municipalities and businesses) in the study area.**

My primary research has shown that the development of linear infrastructure has a significant impact on certain groups in society.

Questionnaire surveys of students and commuters suggest that for both groups linear infrastructure plays an important role, but that this impact differs slightly between the two groups, mainly because commuters have a higher proportion of private transport use.

The local and interurban public transport links in the surveyed municipalities do not provide a consistent picture. Some municipalities have good or excellent public transport connections, while others need significant improvements in public transport. The reasons for these needs are, on the one hand, the bag-type nature of the settlement and, on the other hand, the lack of a fixed rail link, which bypasses the centre of the settlement by a long way.

A characteristic of the settlements studied is that the transport infrastructure between the outer districts of Budapest and the agglomeration is radial, i.e. there are no diagonal and circular connections. In addition, the density of services in some areas is unsatisfactory, with no regular, predictable timetable to provide passengers with an adequate level of alternative to road transport.

- 2. During my research, I proved that the renovation and modernisation of the MÁV and HÉV railway lines serving the eastern part of the Budapest agglomeration has a positive impact on the residents, businesses, municipalities and settlements concerned.**

My primary research shows that the development of the Budapest-Gödöllő-Hatvan railway line will have a positive impact on the life of the settlements concerned and that it is expected that more people will switch to rail transport because of this development. In the case of the settlements located next to and in the immediate vicinity of the railway line under study, the impact of the railway development on the life of the settlement is naturally much greater.

Representatives of the municipalities said that residents have been very patient with the inconvenience of the train replacement during the renovation. The inhabitants all looking forward to the punctual and modern rail service on the rebuilt line.

My research shows that the renovation and modernisation of the MÁV and HÉV railway lines serving the eastern part of the Budapest agglomeration has had a positive impact on local authorities and municipalities.

3. I have scientifically demonstrated that the design and accessibility of public transport in the eastern part of the Budapest agglomeration has a real and demonstrable impact on the daily lives of passengers, and that the impact of the linear infrastructure of train transport is stronger than that of the HÉV.

The daily commute is a daily activity in the lives of people living in agglomerations. This daily process affects a large part of the population. The social and economic processes of the agglomeration and the public transport infrastructure are closely linked. Infrastructure development has a complex impact on the daily lives of people living in the region.

New cooperation in transport management can help to serve better the transport needs within the regions and to ensure efficient and sustainable economic development of the region. My primary research has shown that public transport, in particular public rail transport, has a significant impact on the settlements, communities and people living, working and studying in the eastern sector of the Budapest agglomeration.

4. Using primary research, I have shown that the impact of linear infrastructure in the eastern sector of the Budapest agglomeration is only indirect and not directly significant for economic actors.

Rail transport, which was still significant in the 1970s and 1980s, declined significantly throughout Hungary after the change of regime. Freight transport on the HÉV network was discontinued and the freight wagons were sold.

In the early 20th century, the siding was typically built by companies with a vested interest in and need for rail transport. The MAV network map shows that only one siding has survived in the study area, between Isaszeg and Gödöllő, but its rail traffic is close to zero.

According to the primary research, the priority given to the emergence of rail transport is not significant for the companies operating in the sector under study and interviewed, the rail transport sector is not attractive enough and they do not directly use rail transport in their activities.

The companies surveyed do not have a siding and do not foresee the need for siding in the near future in connection with their activities. For the insignificant number of employees commuting to the companies, rail transport is only occasionally used (rail/HÉV).

5. My research has demonstrated that there is a demonstrable link between the development of linear infrastructure (railways) and economic and social processes in the region under study.

Demographic indicators in the study area have been on the rise in recent years. There has been a significant increase in the size of the population and a high level of migration. The demographic and economic statistics show that the population growth of the agglomeration has accelerated considerably in the decades following the change of regime. In 1970, the agglomeration's population was only 43% of that of Budapest. This proportion has now increased to 68%. Today, around 270,000 cars enter Budapest from the agglomeration every day.

The expected future growth of the agglomeration will generate additional high mobility needs that cannot be met without competitive fixed rail (rail, HÉV) connections. Unfortunately, the quantitative and qualitative improvement of the linear infrastructure has not been realised in Hungary in the last decades, but the recent (2018-2021) development of the railway lines has an important impact on the agglomeration area under study.

In the statistical analysis (factor analysis and binary logistic regression) of the municipalities and their public transport by rail in my research, I found a positive correlation between the renovation of public transport infrastructure and certain demographic indicators.

6. SCIENTIFIC PUBLICATIONS RELATED TO THE TOPIC OF THE DISSERTATION

Book excerpts

In a foreign language

1. **Erdei, A.** – Erdeiné Késmárki-Gally, Sz. (2018): Development of China's railway connections in the 21th century. 27-41. p. In: Neszmélyi Gy. I. (szerk.) *Regional integration and spatial processes in the world*. Gödöllő, Magyarország: Szent István Egyetemi Kiadó. 162 p.
2. **Erdei, A.** (2019): Railway Trade Connections between China and Hungary in the 21st Century. 113-129. p. In: Neszmélyi Gy. I. (szerk.) *The Past and the Future of Hungary's Diplomatic and Trade Relations with East Asia*. Budapest, Magyarország: Budapest Business School, 143 p.

Journal articles

Scientific articles published in foreign languages

3. Erdeiné Késmárki-Gally, Sz. – **Erdei, A.** – Neszmélyi, Gy. I. (2020): Regional aspects of railway passenger transport between Hungary and Romania. *Romanian Review of Regional Studies: Journal of the Centre for Regional Geography*. 16(1) 3-14. p.
4. **Erdei, A.** (2021): Application of electronic ticketing at the Hungarian Railway. *Journal of Tourism Research*. 27 58-68. p.
5. **Erdei, A.** (2022): The protection of train crews during their work in the agglomeration of Budapest. *Studia Mundi – Economica*. 8(4) 17-26. p.

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6. Neszmélyi Gy. I. – **Erdei A.** – Erdeiné Késmárki-Gally Sz. (2018): A rizstermesztés és gépesítésének helyzete Dél-Koreában. *Mezőgazdasági Technika*. 59 (4) 27-29.p.
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9. Erdeiné Késmárki-Gally Sz. – **Erdei A.** – Neszmélyi Gy. I. (2020): A Magyarország és Románia közötti vasúti személyszállítási kapcsolatok történeti áttekintése. *Földrajzi Közlemények*. 144 (4) 363-379. p.
10. Erdeiné Késmárki-Gally Sz. – **Erdei A.** – Grotte J.(2020): A biztonság szerepe a kötöttpályás közösségi közlekedésben Budapest agglomerációjában. *Belügyi Szemle*. 68(11) 89-103. p.
11. **Erdei A.** (2020): Az elektronikus jegyértékesítés regionális kihívásai a magyar vasútnál. *Multidiszciplináris kihívások sokszínű válaszok*. 2 23-42. p.
12. **Erdei A.** (2020): A diákok iskolába járási szokásainak vizsgálata Budapest keleti agglomerációjában. *Studia Mundi – Economica*. 7(3) 2-14. p.

Presentations at scientific conferences published in conference proceedings

In foreign languages

13. **Erdei, A.** (2020): The Future of the Railways in Hungary: More Green Electrification, Less Diesel. 223-227.p. In: Kukharets, S.. (ed.) *Bio-energy Systems: Proceedings IV International Scientific and Practical Conference, May 29, 2020*. 242 p.
14. **Erdei, A.** (2021): The role of security in railway travel in Hungary. 595-604. p. In: Mezőfi N. – Németh K. – Péter E. – Püspök K. (ed.): *V. Turizmus és Biztonság Nemzetközi Tudományos Konferencia tanulmánykötet*. Nagykanizsa, Magyarország: Pannon Egyetem Nagykanizsai Campus. 676 p.

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15. **Erdei A.** (2019): A kötöttpályás közösségi közlekedés szerepe Budapest észak-keleti agglomerációjának múltjában és jelenében. 85-91. p. In: Bálint Cs. – Földi P. – Kápolnai Zs. – Kovács Cs. J. – Nagyné Molnár M. – Zsarnóczky M. B. (ed.): *Rurális térségek a 21. században tudományos konferencia: tanulmánykötet*. Gödöllő, Magyarország: Doktoranduszok Országos Szövetsége (DOSZ) 258 p.

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In foreign languages

16. Erdeiné Késmárki-Gally, Sz. – **Erdei, A.** – Grotte, J. (2020): How does the COVID-19 affect the operation of the Hungarian business environment?: Survey on the COVID-19 impacts’ on the workplaces of the students in Budapest. 29. p. In: Malović, M. (szerk.) *Book of Abstracts International Scientific Conference “Economic Aspects of the COVID-19 Pandemic: How to Survive Today and Cope with Tomorrow”*. Novi Sad, Szerbia : Educons University. 40 p.

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18. **Erdei A.** (2019): Az elektronikus jegyértékesítés regionális kihívásai a magyar vasútnál. 16-17. p. In: Vágány J. B. – Fenyvesi É. (ed.) *Multidiszciplináris kihívások, sokszínű válaszok, 10. Tudományos Szimpózium, Absztrakt kötet*. Budapest, Magyarország: Budapesti Gazdasági Egyetem, Kereskedelmi, Vendéglátóipari és Idegenforgalmi Kar, Közgazdasági és Üzleti Tudományok Tanszék. 109 p.
19. **Erdei A.** (2020): A vonalas infrastruktúrák társadalomformáló szerepe Budapest keleti agglomerációjában. 289. p. In: Barna B. J. – Kovács P. – Molnár D. – Pató V. L. (ed.): *XXIII. Tavasz Szél Konferencia 2020. Absztraktkötet: MI és a tudomány jövője*. Budapest, Doktoranduszok Országos Szövetsége (DOSZ). 600 p.