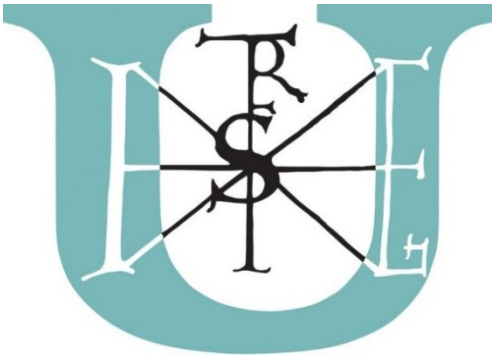

SZENT ISTVÁN UNIVERSITY

The role of trams in Budapest from a regional perspective

DOI: 10.54598/000410

Theses of doctoral (PhD) dissertation

Péter Takács
Gödöllő
2021

Doctoral school

name: Doctoral School of Economics and Regional Sciences

Discipline: regional sciences

Head: Dr. József Popp
university professor, correspondent member of the Hungarian Academy of Sciences,
Doctor of the Hungarian Academy of Sciences
Szent István University (SZIE), Faculty of Economics and Social Sciences, Institute of Agribusiness

Supervisor: Dr. Tamás Tóth
university professor
SZIE, Faculty of Economics and Social Sciences, Institute of Agribusiness

…….. ……
Approval of head of school Approval of supervisor

Table of Contents

1. BACKGROUND OF THE WORK, OBJECTIVES

Regionalism and transport are closely related concepts. The goal of regional development, among others, is to reduce unemployment, demographic pressures in overcrowded city centres, to compensate development disparities, and to protect the environment. The primary function of the settlements is to provide optimal spatial and technical conditions to society, while having specific features that are unique to them (TAKÁCS 2019). One of the basic requirements for the operation of cities is social mobility and relocation within and between settlements, in a quality having a direct impact on development and the quality of life. Transport, therefore, provides an essential service background for the functioning of the economy and the society. Its task is to create mobility for people, goods and services, and in connection with the fulfilment of higher-level expectations, the aim is ultimately to promote economic development and balance territorial inequalities (BKK 2014). In Europe the share of the urban population is constantly growing and will approach 75% by 2020 (UNITED NATIONS 2020). Urbanisation is accompanied by a growth in the number of vehicles and commuter traffic, which is causing increasingly serious traffic problems. The decision-making bodies of the European Union have also recognised the connection between the quality of life in cities and the development of the transport system therefore they encourage the preparation of sustainable urban mobility plans (JANKÓ 2019). The aim of these measures is to support the more efficient and sustainable use of existing transport infrastructures and the improvement of the quality of services provided on them. Thus, in addition to improving the quality of life in the given area, the reduction of the environmental load of the transport system also appears as a priority goal, that is, cities have a responsibility to improve mobility in a sustainable way, reduce the number of accidents and pollution, reduce travel times and minimise traffic congestion. In addition, a significant regional development effect can be achieved through transport development, as its contribution to GDP is also significant.

At the same time, these complex and competing goals raise the question of which aspect of transport development is more important: whether to ensure mobility (including the less affluent groups of society and the expectations of people with disabilities, which are of paramount importance in the process of territorial equalisation), or to protect our environment and health (this service has

a significant environmental impact, e.g. greenhouse gas emissions, noise and vibration exposure, use of space, etc.). The common goal of the European Commission and the Hungarian Government is to ensure freedom of movement, health, safety, good quality of life, environmental efficiency and inclusive economic growth in a way that everyone can access the services. In light of this, we must also seek and support solutions for transport development that meet these double expectations.

The priority given to public transport helps to meet the environmental and health aspects, as it is more in line with the objectives than the individual modes of transport, with its more favourable need of space, lower environmental impact, affordable price and better accident statistics. In places where the road railway (tram) is in competition with road vehicles (bus), the aim is clearly to give preference to the former. There is room for public transport in European cities, and the strengthening of its privileged role can be predicted mainly in the field of rail-bound urban transport. Unfortunately, at the same time we cannot ignore our capabilities and room for manoeuvre in our decisions; in order to broaden the boundaries, it is also essential to pursue the idea of efficiency gains and to explore the possibilities. In Hungary and Eastern Europe the change of regime brought several positive changes in terms of public transport and regional development, yet they inherited, among others, aging vehicles fleets, which has posed many challenges for the operators.

In my dissertation I focus on the segment of tram transport within public transportation that affects regional approach, and I discuss concepts such as settlements, urbanisation, transportation, excessive operation and environmental protection. The focus of my research is on the connections existing between transport and the environment, the reasons for preferring road railway, finding good examples, tackling the problem of excessive operation and increasing efficiency. My main goal is to examine the role of public transport, including road railway (tram) in Budapest, in the three decades following the change of regime in relation to the features of urbanisation and the settlement system.

1.1. Rationale and topicality of the research subject

Several research have already dealt with the relationship between the public transport systems and the historical development of cities. Today, however, the intensification of urbanisation processes, the emphasis on environmental protection and sustainability goals, the emergence of alternative technological solutions, the role of public transport in the liveability and development of cities are all factors which require the continuation of up-to-date research with a new focus on the development and operation of transport.

In my dissertation I undertake a regional approach to the development of road railway transport, during which I examine the key issues of trams in relation to their mobility and sustainability goals, and their operational challenges. Accordingly, for Budapest, I identify the main developmental periods of this mode of transport in the light of regionalism, present its place and role in transport development, and examine its economic characteristics, and its social and environmental effects. It is also essential that, in addition to the urban and transport development objectives, I also carry out an analysis of the operational effects and management options of overused vehicles when examining the potentials of road railway. Accordingly, focusing on Budapest, I describe and analyse the practice, effects and management possibilities of operating trams beyond their useful life. While domestic and international literary research usually analyses the main trends and factors separately, in my opinion, there is a lack of integrated management and joint examination of these issues, and the analysis of the issue of operation beyond the useful life fails to get enough emphasis in the literature. My aim is to provide systemic support for prioritising road railway on a regional level, approaching the challenges and opportunities of road rail from several angles.

The conducted examinations focus primarily on Budapest and BKV Zrt., (the Budapest transport company), but I also performed domestic and international comparisons to interpret the analyses.

1.2. Objective and research questions of the dissertation

The general aim of my dissertation is to support the more efficient and sustainable use of the transport system and the improvement of the level of service they provide, on the one hand, by identifying the main challenges and opportunities for road railway (tram) transport and by examining in a systematic way the main aspects of operation beyond the planned service life, which is a critical point in the operation of these types of vehicles; and on the other hand, by developing tests and methods to help resolve problems with overused vehicles in service practices, which can be a useful tool in supporting the transport service providers' investment and operational development decisions in this area. Along with all these general objectives (O), I formulate the following research sub-objectives:

O1: Analysis of the role of road railway transport in regional transportation and urban development in Budapest.
O2: Carrying out an international analysis to explore territorial disparities between cities and transport providers.
O3: Analysis of the Hungarian practice of operation beyond the useful life and formulation of recommendations.
O4: Examination of the relationship between operation beyond the planned service life and the cycles determining the maintenance and overhaul of trams, and formulation of proposals.
O5: Analysis of the possibility of optimising the vehicle portfolio from the point of view of operation, including overused equipment, and formulating proposals.

In line with my research goals, I seek answers to the following main questions (Q) in my dissertation:

Q1: What connections can be identified between settlements, urbanisation, society's expectations, technology and transport, and urban development in Budapest? How has the operation of road railway in Budapest changed from a regional point of view from the beginning to the present day?
Q2: What differences and similarities can be discovered in the operation and connection system of each city and its transport service provider?
Q3: Given the main challenges of sustainable development and mobility, which public transport sub-sector is preferable?

Q4: What is the relationship between excessive operation of the vehicle and costs, failures and accidents?

Q5: Can the efficiency of road railway be increased by optimising operational practices (timetable preparation and car release)?

Q6: What aspects and factors need to be considered in connection with the operation of vehicles beyond their planned service life? How does the operation of vehicles beyond the planned service life appear at the Hungarian railway companies? In what directions can the Science-Based Continued Operation Protocol of BKV be further developed?

1.3. Hypotheses (H) of the research

Based on my objectives and research questions, I formulated the following hypotheses at the beginning of my research:

H1: The development history of the Budapest road railway transport system can be divided into sections that can be characterised by unique features based on regional approach, and in this process of development history, the main turning point in respect of broadening the regional approach and the dramatic change in the basic processes of the transport service is represented by the change of regime.

H2: Although there are a number of historical, economic, social and political reasons for the inequalities between the capitals of the Visegrad Four (V4) and Vienna's public transport systems due to the co-evolutionary link between cities and transport development, in terms of transport management and operation activities, their efforts and characteristics with regard to meeting urban mobility needs in a sustainable and liveable way point in a common direction.

H3: There is a significant relationship between the excessive operation of trams and the number of failures and costs, however, the relationship between the excessive operation and the number of accidents cannot be verified in Budapest. The planned service life specified by the manufacturers is not relevant on the basis of the tests results.

H4: Given that, based on their social, economic and environmental impacts, it is justified to give priority to road railway among urban public transport modes, an optimal car release scheme can be developed along with the

excessive operation of trams, which supports the increase of road railway efficiency.

H5: Despite the fact that of the domestic public transport service providers with road railway equipment and infrastructure only BKV Zrt has a declared, science-based methodology developed for the purpose of operation beyond the useful life, the examination of the technical and risk aspects of the excessive operation of trams is an integral part of the practice of all public transport providers.

2. MATERIAL AND METHODOLOGY

2.1. About the methodology and databases of the research in general

Regarding the methodology of the research I conducted it can be stated that the dissertation is primarily based on secondary research, both in terms of literary review and the individual empirical analyses. I consider it important to note, however, that the lack of theoretical and empirical examinations and secondary data on the operation of equipment and vehicles in excess of their planned service life has made the work significantly more difficult. Given that in my dissertation I aimed to answer the questions that arose during my everyday work, I also started collecting data and information there. The IT system of BKV Zrt is based on the SAP corporate governance software package, which also collects the company's economic and technical data in an extensive way. The units of my analysis basically include the statistics of BKV (cost, failure, accident, etc.), which contain a sufficiently large amount and appropriate hierarchy of time series data for the examinations. In addition to the analysis of internal information, I relied on the databases of public transport companies, international organisations and EUROSTAT in a regional comparative examination. At the same time, I examined the operating practices of the companies operating the Hungarian road railway vehicle fleet beyond the planned service life by conducting primary research and conducting expert interviews.

The methodology of my dissertation is basically deductive, but it is supplemented by inductive research elements, since by analysing the sources, documents and previous experiences and looking for connections, I try to formulate novel regularities. In the dissertation I use both qualitative and quantitative examinations. In the course of international and domestic comparison I perform document analysis, i.e. I seek to explore the correlations that can be actually identified in local spaces in an empirical way with the method of direct data collection and data analysis. In contrast, in examining the effects of excessive operation, I use correlation, regression, and trend analyses to identify the relationship between the factors included in the study, and I perform optimisation of car release to increase the efficiency of road railway by means of linear programming.

2.2. Structure of the dissertation

The structure of the dissertation is illustrated in Figure 1. In the first sub-chapter of the literary review (second chapter) I discuss the relationship system of the urban-urbanisation-transport concepts (based on the works of BELUSZKY, 1973, ENYEDI 1997, 2011, BERÉNYI 2012, KOVÁCS 2017, KÁPOSZTA 2018), with special attention to identifying the urbanisation periods of Budapest.

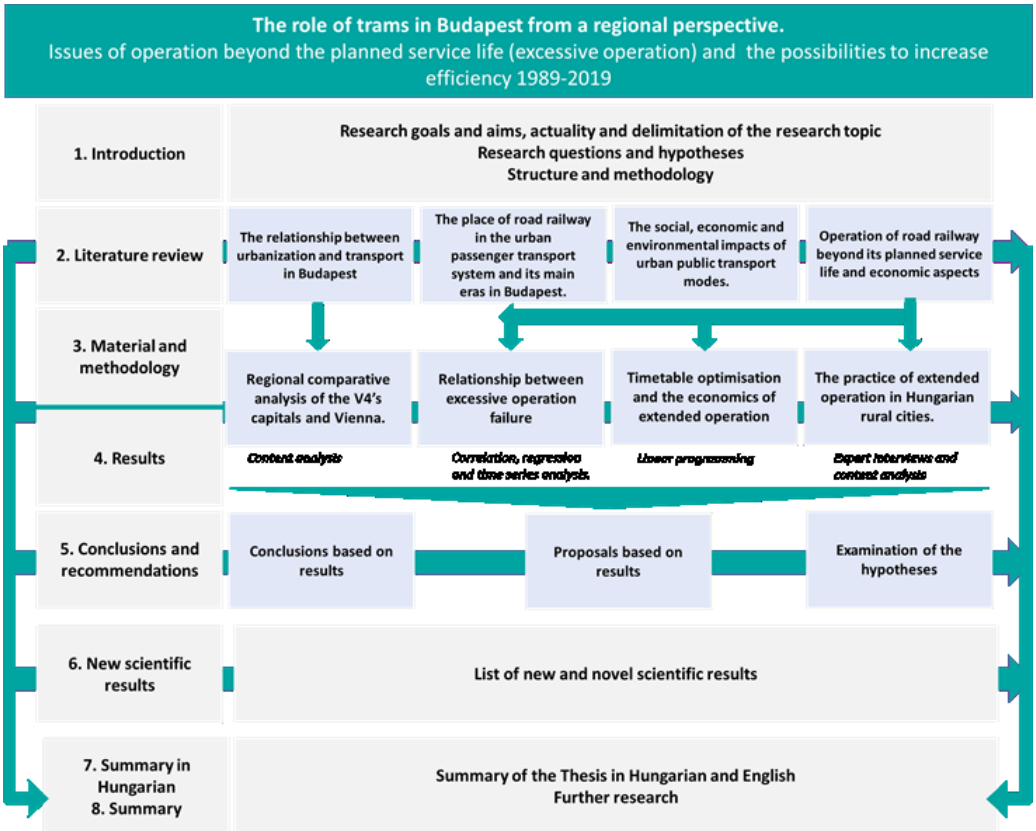

FIGURE 1.: STRUCTURE OF THE DISSERTATION
Source: Own edition

In the second sub-chapter, I focus my examination on the co-evolutionary relationship between cities and transport development, and relying on relevant literary sources (e.g., HADJILAMBRINOS 1998, GEELS 2005, KAIJSER 2005, OTTENS ET AL. 2009, AUVINEN-TUOMINEN 2014), I present the

possibilities and contexts for the interpretation of the urban transport system as a socio-technological system.

In the third sub-chapter I describe the place of road railway (tram) in the passenger transport system and identify the main developmental periods of the Budapest road railway transport system in a regional approach. During the historical review I interpret the period of regime change as the main turning point, in which the regional approach becomes decisive, and which induces significant changes in the field of transport services and in the strategic and operational functioning of BKV Zrt. In connection with the challenges of the present, I examine the emergence of regional approach in transport development and the changes in expectations towards the transport system.

In the fourth sub-chapter, starting from the sustainability requirements for the transport system (see e.g. HALL 2009, EC 2009, MILLER ET AL. 2016), I systematize the main social, economic and environmental characteristics of urban public transport modes and vehicle types, thereby establishing a preference for road railway as an urban public transport mode.

I dedicate the final, fifth sub-chapter to the issue of and the tasks related to excessive operation already mentioned at the beginning of the introduction, with a focus on economic aspects.

In writing this dissertation, in addition to taking into account the negative technical features, risks, and economic impacts, I primarily focus on practical solutions to what operators do and can do to address problems.

Based on the theoretical foundations, in the second major unit of my dissertation I cover the main research areas, goals and methods examined in the dissertation, followed by a chapter discussing the research results of each study and analysis, which can be found in the third and fourth chapters of the dissertation.

I have divided my practical research into four parts, the reason for which is rooted in the problems that arise in my everyday work. As a decision-maker working in the field of railway operation, I consider the negative features of the area, which result from the operation of vehicles beyond their planned service life, to be emphasised in relation to the Budapest tram sector. Of the approximately 600 trams currently operated in Budapest, more than 500 significantly exceeded their originally planned operating time (30 years), with an average age of 40.5

years, but we also find vehicles older than 50 years in the fleet. This circumstance cannot be ignored when comparing the traffic indicators of Budapest or the operation of BKV with the indicators of other cities or other transport companies. I carry out my entire research in the knowledge of these system characteristics, looking for new possibilities and results that can alleviate the effects of this aggravating factor.

First, starting from the regional peculiarities of the transport systems, I analyse the transport system of the Visegrad Four and the Austrian capitals, the activities of their service providers and the identification of the differences and similarities in the operation of the equipment in order to find the best practice.

Next, in view of BKV's overused vehicle fleet, I focus on the main issues of the operation of the road railway fleet beyond its useful life, within which I examine the connections that can be discovered between the excessive operation of trams and the figures relating to costs, failures and accidents.

In the third part of the research, looking for the possibility of optimising daily car release, I analyse the possibility of economical operation beyond the useful life, in which I focus primarily on the new approach.

Finally, I analyse the experiences and measures of Hungarian rural railway companies in relation to the practice of operation beyond the lifecycle.

In the fifth chapter I synthesize the results of the dissertation, describe its main conclusions, and summarize the responses to the hypotheses.

Finally, the dissertation concludes with a summary of the new scientific results (sixth chapter) and a summary in Hungarian and English (seventh and eighth chapters).

2.3. Elements and characteristics of the road railway operated by BKV

Railway systems are characterised by their high value of investment assets, the maintenance of which is a complex and costly activity. When ordering new vehicles, the operators provide the parameters specific to the given city and track as basic technical data, which practically necessitates the development of unique, individual types. Thus, the vehicles being made for Budapest are not pieces of a prefabricated fleet that can be ‘removed from the shelf’, but products specially

developed and manufactured for Budapest. The railway track and infrastructure are also site-specific, which in many respects justifies individual design, development, and construction. Due to this although the road railway systems are similar, they differ from region to region and even from city to city. Due to their differences it is difficult to compare them and based on different features (e.g. topography) and needs (e.g. climate), their costs and operability are also different.

In the case of BKV, the performance of the road railway system is covered by the fleet itself with the total number of runs they can perform, of which, in addition to the number of units, availability is the most significant component. As of 31 December 2019, the tram passenger car fleet operated by BKV's tram sector can be characterised by the following:

- 9 vehicle types,
- in total 584 vehicles,
- the average age of the fleet is 35.44 years,
- 87 vehicles below the age of 30 years (3.2-13.5 years)
- 497 vehicles over the age of 30 years (34.9-52.3 years!)
- the planned useful life of the trams is 30 years.

In addition to vehicles, the priority areas of railway infrastructure are railway tracks, structures and bridges, telecommunications and signalling equipment, energy supply networks and transformer stations, as well as buildings not detailed here. Based on the above it can be stated that BKV's tram fleet and infrastructure, measured by European standards, cover a system of significant size with extensive network, typically consisting of obsolete, overused, and heterogeneous elements. In any case, the most important feature is operation beyond the planned service life, as it necessitates the majority of tasks and activities.

2.4. Operation beyond the planned service life at BKV Zrt.

At the BKV Railway Directorate, starting from April 2014, decisions to further operate equipment aged over their useful life are made on an objective basis using a complex test methodology (taking into account both technical and economic aspects) developed and approved for this purpose (Science-Based Continued Operation Protocol – SCOP). This methodology requires the operator to perform pre-defined, detailed measurement and evaluation tasks for specific equipment (FIÁTH ET AL. 2016). Using the developed system, the operator, after

performing a special (TPP) test for assets exceeding their useful life and evaluating its results, has the opportunity to continue to operate the equipment according to the following options:

- the equipment can be operated without further intervention for a period of 2 or 3 years in the light of the results of the test (the measurement results are satisfactory, the intervention – critical – value is not reached);
- the asset can be further operated for a period of time determined by the examination (the measurement results do not meet, reach or exceed the intervention – critical – value) after performing the interventions determined based on the examination results (replacement or reinforcement of certain parts and elements). After the interventions have been completed, the asset can be further operated for a period of 2 or 3 years;
- the asset can no longer be operated in the light of the results of the examination because it is not economical to proceed with the necessary interventions.

It can be stated that the TTP introduced by BKV is a useful decision support tool, the use of which helps responsible operation.

In connection with excessive operation, one of the sub-objectives of my research was to explore the practices of rural companies operating domestic road railway systems in terms of the system of operational activities of the equipment and how to characterize the internal regulation of these activities. Accordingly, I seek to answer to the following questions:

- Do rural service providers use a methodology similar to the BKV method, which supports the Scientific Continued Operation methodology, and is the possibility of excessive operation taken into account in investment decisions?
- What are the options to develop and fine-tune the TTP applied at BKV?

To conduct the examination, I chose to interview experts via semi-structured interviews. The main argument in favour of using semi-structured interviews is that the draft interview used in these cases, as a guideline for the discussions, provides an opportunity for both the interviewer and the interviewees to remain with the main topic during the interview, while being flexible enough to address secondary issues related to the key issues.

In my dissertation I examine the effects and significance of excessive operation in an international comparison – in the course of territorial study – and also on the basis of Hungarian practice, and I formulate proposals for the further development of TPP.

2.5. Methodology of the regional study

In my everyday work I seek to answer the question where the differences in the operational efficiency of public transport providers may come from. These service providers appear to operate under a similar set of conditions and operational logic, but with different efficiencies in respect of their results. Although the amount of transportation service ordered by cities is essentially a function of geographic and demographic data, and the organisations serving it are created in the form of a business company, we still find differences in actual implementation. The identification of the operational characteristics and main challenges of BKV, as well as the exploration of development opportunities, also necessitate an international comparison. By exploring the differences, the results of the service quality and passenger satisfaction surveys can be explained, and the possible intervention points can also be identified. I chose the public transport systems of the V4 capitals because, based on their size, features, history, economic development and location, these cities are suitable for international comparison. According to my hypothesis, although the coevolution of individual cities and their public transport system follows a unique development trajectory, the differences caused by territorial inequalities, taking into account the public transport systems of the capitals of the Visegrad Four countries, are insignificant. During the research, the public transport system of the city of Vienna can be used as a best practice and a reference for the purpose of identifying the differences. The following factors were decisive in selecting the specific units of analysis:

- coincidence of research purpose and availability,
- similar geographical, historical, economic and social characteristics,
- capital city – countryside comparison,
- advanced – less developed economic environment comparison,
- significant experience and transport provider focus.

I used the method of document analysis to conduct an exploratory descriptive examination. The data required for the analysis come from the studies and official

data provided by the examined transport service providers and international organisations.

2.6. Correlation analysis methodology

At BKV the maintenance and overhaul of electric vehicles is carried out in accordance with the provisions of the company standard adopted by the authorities *('Cycles for the maintenance and overhaul of railway and other rail-bound vehicles operated by BKV ZRT.')* (Hereinafter: cycles).

The cycles are based on the manufacturer's recommendations, the design features of the vehicles and the operational experience gained by BKV and provide the basis for the company's vehicle maintenance and overhaul tasks.

The vehicle maintenance system is based on planned, cyclically repetitive activities and stages, where the higher-stage activity also includes the lower-stage maintenance elements. These tasks, as well as the task of occasional repairs, are performed by a suitably competent maintenance staff of the remise operating the specific tram.

In my dissertation I conduct a large number of statistical analyses based on

- observations (approximately 600 trams), and
- units of analysis (time series data on costs, failures, and accidents in BKV's SAP system, approximately 250,000 pieces of data)

(correlation study), based on which the revision of the cycles applied at BKV becomes supportable.

Adapting the cycles to a specific vehicle (based on analysis, with its main operating characteristics known) increases the efficiency of vehicle maintenance and could reduce operating costs.

2.7. Methodology for optimising tram car release

Road railway companies are looking for optimisation opportunities in their timetable-related car release to meet increased and changing performance requirements, primarily to reduce their costs. The operation of the increasingly extensive tram and metro network holds a number of optimisation opportunities that evolve over time with spatial and temporal changes. In the course of the analysis I examine the extent to which cost reductions can be achieved during

operation by optimally distributing vehicles on the current Budapest road railway network (in terms of cost utilisation), while customer requirements are also met. As the operating costs of the different types of trams are different, it can be considered optimal if in each case in the given daily timetable we keep in circulation the vehicles with the lowest costs.

BKV provides its services in Budapest in the framework of a public service contract ordered by BKK Zrt. There are a number of aspects to consider in terms of the possible optimal fulfilment of order, related in a rather complex manner. The mathematical modelling of the problem is based on linear programming methods but compared to the approach used so far for timetable optimisation tasks, this task is less complex. Local characteristics (e.g. weight and size limits) justify special mathematical modelling that can avoid over-determination during linear programming. If the Budapest tram network is considered homogeneous, and the number of different vehicle types is considered variable, then a minimum task can be set using the corresponding HUF/placekm values. This minimum task can be accomplished by the simplex method, however, the optimum given by the programme will not be fully applicable to the specific case, as traffic constraints have not been taken into consideration. When applying the model, it is necessary to check the actual practical applicability of the result ‘manually’, also taking into account the special factors.

During the examination I define the goal of optimisation and gather the factors that need to be taken into account when creating a decision support model, and perform an operator-oriented, cost-reducing, conceptual optimization study of daily timetables.

3. RESULTS

The purpose of this chapter is to describe the results of my analyses in part as follows:

- Based on the regional specificities of transport systems I analyse the transport system of the capitals of the V4 countries and Austria, primarily to identify differences.
- Regarding tram transport in Budapest, in connection with excessive operation, I seek to find correlations with the effects of operation beyond the useful life on costs, failures and accident rates, to review cycles.
- I analyse the possibilities of optimising tramcar release in daily timetables, primarily in terms of cost savings.
- Given that the Hungarian road railway operation is generally characterised by operation beyond the planned service life, I also examine its practice in comparison of rural cities and Budapest.

3.1. Test results for the characteristics of public transport in Budapest in international comparison

My analysis compares the characteristics of the public transport systems operating in the capitals of the Visegrad Four (Budapest, Bratislava, Prague, Warsaw) and Vienna, typically in order to determine the situation in Budapest and to identify the differences.

Overall, based on the study it can be stated that, in the case of Budapest in a different manner, the role of transport integrator extends only to the administrative border of the capital, which is unfavourable from the point of view of regionalism and integration.

In the Hungarian capital, the proportion and volume of public transport can be said to be significant, which is also confirmed by the comparison.

In terms of funding, the proportion of funding per passenger is low (approx. half the average of the other cities), due to which – in part – the proportion of obsolete and outdated rolling stock is exceptionally high, which has a detrimental effect on the quality of service.

Surprisingly, despite the difficult circumstances (financing and overused equipment), and according to passenger satisfaction surveys, the passengers are mostly satisfied with the transport service in Budapest, which does not stand out from this comparison.

The tasks of the transport managers of the capitals of the V4 countries and Austria generally appear separately from the transport service, which is an international trend and an efficient solution. It can be said that it is expedient to evaluate and satisfy the transport needs of the city and its agglomeration in a regional approach, which is also characteristic for the examined settlements.

3.2. Examination results for the effects of excessive operation

In the case of road railway vehicles, the main dimensions of operation beyond the useful life are represented by the mileage of the vehicle (wear dimension) and the age of the vehicle (time dimension). Accordingly, I describe below the relationship that can be identified between these two dimensions and the evolution of vehicle-related defects and costs based on my analyses.

During the tests I assumed that mileage has an effect on the number of failures (M1 error: failure of vehicles in traffic not causing a malfunction, M2 error: failure of vehicles in traffic causing loss of service), and also has a significant impact on cost developments. My further assumption was that costs are influenced not only by the mileage, but also by the number of failures.

In my dissertation out of the 510 correlation analyses and linear regression analyses performed for the examination period (2003-2019), due to their volume, I present only those where stochastic relationship could be identified.

As a result of the test it can be concluded that the correlation between M1 type errors and mileage is suitable to characterize the actual reliability of the given type by which the useful life can be determined.

The independence of the number of M2 faults from mileage is a good indicator of the high quality of maintenance, from which it also follows that this parameter is suitable for judging the quality of operation.

Based on the results of the examination of material and personnel costs it has been concluded that the determination of the root cause is essential in a thorough, comprehensive analysis, as their relationship to age has not been established.

My research objectives also extended to the examination of relationships between the number of accidents and the operation of trams beyond their useful life. I found that there was no significant quantitative change in the relevant accident rate of electric vehicles during the period under review, i.e. between 2003 and 2019 the accident rates had a nearly constant value. Based on the above, the results of the study show that in the case of trams no significant relationship can be identified between overrun and the number of accidents.

3.3. Theoretical optimisation of tram car release in Budapest

As I mentioned earlier, a significant part of BKV's tram fleet is outdated and fails to meet the requirements of the age and the expectations of passengers. Ideally, vehicles that have exceeded their useful life, but at least some of them, should be replaced by new or novel vehicles (at least equivalent to CAF5 tram). However, due to geometric and weight limits that are currently not easily manageable, as well as recent high-value vehicle upgrades, it is reasonable to further operate the fleet of UIA (upgraded industrial articulated) trams and upgraded T5C5 trams. With the former in mind, one can calculate with a 'realistic' fleet composition that is still far from ideal, but already more cost-effective than the current one.

BKV provides its services in Budapest in the framework of a public service contract, ordered by BKK Zrt, based on quantitative and qualitative parameters. The quantity of the order is practically the performance that the customer intends to buy place kilometre, and its quality expectations are primarily related to ensuring equal opportunities and air conditioning. The Tram Directorate of BKV Zrt operates nine different types of trams at nine tram depots, which show significant differences in respect of technical condition. The structural design of the vehicles is decisive for the fulfilment of the order, which mainly concerns the low-floor design and air conditioning, but also includes additional aspects (e.g. vehicle maintenance). The infrastructure features of the capital appear implicitly in the elaboration of the task, as they represent physical constraints in operation (including, for example, weight and gauge constraints).

When optimising service performance, BKV must consider the availability indicators resulting from the technical condition of the vehicles and the specific costs of the vehicle types. It can be seen that an efficiency-enhancing task involves

a large number of subsystems, with a number of one-off and ongoing cost elements.

The companies operating tram railways seek to find optimisation opportunities in their timetable-related car release to meet increased and changing performance requirements, primarily to reduce their costs. Since the primary goal of optimisation in our case is cost-effectiveness, and making decisions requires complex knowledge, therefore reliance on a decision support model could make it easier to increase efficiency in this area.

In my examination I define the goal of optimisation and gather the factors that need to be considered when creating a decision support model. The examined cost optimisation option aims to explore savings opportunities during the implementation of the daily timetable and to simplify decision-making, taking into account regional development goals. The reorganisation of daily tramcar release operated at different cost levels and well-planned investments offer the opportunity of significantly reducing operating costs.

A model-like examination of the theoretical possibility showed that with well-thought-out organisational and investment activities, up to hundreds of millions of forints per year can be saved in this field.

3.4. Test results for the excessive vehicle operation practice of the rural urban transport companies operating the Hungarian road railway

The asset requirements and operating costs of urban railway companies are significant. Given that investment cooperation between the companies and the owner local governments does not follow the same approach, sometimes the emphasis shifts. One thing will be important to one and a different one to the other, which may eventually lead to intermediate solutions. The utilisation and efficiency of rail-bound transport equipment varies from region to region.

Cities essentially go two ways in their equipment replacement investments: either refurbish or replace vehicles that have reached the end of their planned service life. Further operation of a vehicle ready for replacement without refurbishment seems like a necessary solution, but its effectiveness in a regional approach is unquestionable.

The examined rural urban railway companies are significantly smaller in size than BKV, the total number of their railway vehicles does not reach the number of vehicles maintained and operated by a Budapest remise, and the amount of their infrastructure assets is significantly smaller. Due to their size, it can also be assumed – as it was validated during the interviews – that the volume of equipment beyond the useful life of the operated assets is smaller compared to similar equipment operated by BKV. Nevertheless, all rural transport companies hold equipment in excess of their useful life, but their amount can be considered small in all three affected cities (Debrecen, Miskolc and Szeged) or, based on different accounting practices, there is also a difference in their useful age.

Based on the interviews it can be stated that rural railway companies are in a much better position in terms of the practice of operating beyond the useful life than BKV.

Overall, in the light of the information received at the consultations it can be stated that none of the rural railway companies applies a methodology comparable to the TPP operating at BKV, which specifically supports the further operation of equipment over their useful life. The further operation of such equipment will continue along with maintenance in accordance with the original manufacturer's technology, considering the operator's experience. During the maintenance of the equipment no additional activities are carried out which, based on the current practice, is not considered justified.

The BKV TPP model is a complex, scientifically established methodology that also takes into account experiential knowledge. It is unique, as currently other Hungarian tram companies do not even use a similar model. Its modules are built on top of each other, they fit together organically, but at the same time the technical module can perform its decision support function when used alone. It is user-friendly, and its application consists of a series of steps logically built on each other. The application of TPP can increase the quality indicators of operation and at the same time make it possible to detect the amount of additional costs resulting from the lack of renewal of the assets that are, however, essential for further operation. It is suitable for the fulfilment of obligations provided for in the Public Service Contract (quality indicators, operation and maintenance of vehicles and infrastructure, renewal of equipment).

The aspects of fine-tuning the TOP model naturally stem from the weaknesses of the model, the two main elements of which involve disregard for lifecycle costs and inappropriate accounting. In the context of further operation it can be said that it is not enough to make a decision solely on the basis of an assessment of one-off investment costs, but it is necessary to take into account all the costs incurred during operation. When examining investment alternatives, we exercise due diligence if cash flows over the entire lifecycle are analysed during construction or renovation.

4. CONCLUSIONS AND RECOMMENDATIONS

In my dissertation, I formulate conclusions based on the results in the light of my research goals, questions, and hypotheses. I examine the regional explanation for the role of road railway by identifying its periods as a socio-technological system in relation to Budapest, where I interpret geographical and social characteristics along with urbanisation. Together with the environmental impacts of urban public transport modes and operation beyond the planned service life typical in Budapest, I determined the direction of practical investigations as a negative factor. In general, my goal was to offer an international outlook and to analyse the impact and practice of excessive operation, as well as to explore optimisation opportunities. I evaluate the research hypotheses in the order of the chapters, together with the related studies.

4.1. Conclusions of the research related to the development of the Budapest railway transport system and the identification of its specific features

To examine the connections between regionalism and public transport I consider it essential to have an overview of the history of development, in the framework of which I can identify the characteristics of the specific periods. It is my view that the regional approach, which is expanding to the present day, is the consequence of a multi-stage transformation, during the analysis of which I can identify its most significant period. My aim was to explore the connections between urbanisation processes, social expectations and technology in Budapest from a regional perspective, as well as an international perspective to explore territorial inequality in relation to the co-operation existing between cities and their transport service providers.

In connection with the research, I sought answers to the following questions:

- Where is road railway placed in the passenger transport system and how has it changed regionally from the beginning to the present day?
- What connections are there in respect of settlements, urbanisation, society's expectations, technology and transport, and urban development in Budapest?

- Whether the transport systems of some European capitals similar to or comparable to Budapest are fundamentally different, and what are the differences in the operation and the connection systems of cities and their transport service providers, and how typical is regional approach?

Road railway is a surface-driven, motorised, collectively used, public rail-bound transport sub-system of the urban passenger transport system. As part of this system, it is a key element of services to meet the mobility needs of the city and the agglomeration. The three eras defined in relation to road railway transport – from its appearance in 1866 to the end of the Second World War, from 1945 to the change of regime in 1989, and from 1989 to the present day – have been identified in the light of society's expectations, from a regional perspective.

It can be concluded that the changes in the needs of society are covered by the concepts characteristic for regional development, the expansion of which is shown in Budapest by the examined periods. In Hungary, in connection with the change of regime in 1989, ideas emerged allowing space for regionalism in the spirit of the intention to join the European Union, with the potential to strengthen the goals of sustainability and environmental protection in urban development. The changes in BKV associated with this period are the result of a paradigm shift that led to a Fordist-post-Fordist transformation.

In this context, it can also be stated that the strengthening of urbanisation processes in Budapest forced co-evolutionary and regional transport and urban development. Accessible, reliable, affordable, safe, convenient, environmentally and user-friendly transport services indirectly contribute to improving the liveability of cities. Interpreting transport as a socio-technological system it can be said that its development is closely related to urbanisation periods and technological changes. With regard to Budapest, it can also be stated that the need for connecting the separated urban and suburban functions helped to spread the regional approach and to expand road railway.

The international outlook provided an opportunity to explore differences in the operation of cities and transport providers. During the examination the factors that cause inequalities became identifiable, so the points of intervention can be explored and suggestions can be made. The mobility needs of the ever-expanding urban areas extend beyond administrative borders, so there are organisational tasks emerging at the regional level in connection with public transport systems.

The need of the people living in a conurbation town but working or studying in a big city points to creating a community service with a unified approach and adequate quality of service. The development of organised public transport systems can also reduce the burden on the urban environment. Taking into account unity and regionalism, it is typical for Europe that the regions create integrator organisations for ordering and organising transport services. Their task is to develop an attractive, passenger-friendly, coordinated and transparent public transport service by matching supply and demand in order to meet the mobility needs of a given city and its agglomeration. It can also be seen from the examples of the examined areas that the public transport activities are increasingly carried out in a regional approach. Thus, the regional area of operation of the transport management activities typically extends beyond the city boundaries. A unique exception is Budapest, where there has been a regress in the unity of the transport system over the recent period. In recent years, the state has taken over the task of ordering agglomeration public transport, so the division of the boundaries of activity and competence has also resulted in a kind of duality, but by no means a uniform, integrated system. Based on the examples it can be stated that the aspects of unified approach, economies of scale and territorial development cannot ignore the principles of regional policy in performing these tasks. The implementation of these principles (decentralisation, subsidiarity, partnership, additionality, programme funding, inter-regionality, sustainable development) should be prioritised along the objectives and the interests should be kept in mind in a broader sense.

It can also be seen that the local governments typically own the most important public transport service providers operating in the capitals, ensuring their local interests through them and an appropriate contractual system; at the same time, this does not preclude transport integrators from operating at a broader, regional level and defining the requirements for capacity sharing, coordination and tariff community required for integration (Budapest is an exception with regard to the examined cities).

Regarding the financing structure of public transport, it is typical for the examined cities that the rate of operating compensation is over 65%. Unfortunately, this is not justified in the case of Budapest (and Bratislava); moreover, the amount of revenue from financial support is significantly lower than the similar sources of the systems operating in Vienna, Prague and Warsaw.

This is especially noticeable if we examine the ratio of revenues per number of passengers, because in the case of Budapest, with a high passenger traffic value, there is a relatively low financing (and thus total revenue) structure.

It can also be observed that in addition to the service providers with a state or local government ownership background, an increasing number of private companies are emerging, especially in the bus sector. This also means a kind of competitive situation, especially for integrator organisations with a wider area of operation (e.g. Vienna, Prague). In Budapest, the transport integrator BKK orders some of the bus services it needs from non-local government owned service providers. The issue carries an interesting division, since if the local government acts as a customer, then it seems appropriate to solve the needs of mobility within the city using a self-owned service provider, however, if the service area, and thus the customer task, extends beyond the administrative boundaries of the big city and represents regional aspects rather, a competitive situation between the service providers may prevail.

Budapest plays an important role in the net line length and the number of routes (about 1,150 km and 250 routes). Based on passenger numbers and place kilometre data, it seems that the supply provided by the public service in Budapest most effectively meets the demand, but in the case of other cities the less efficient data may be due to the less efficient demand-supply ratio of agglomeration services. Budapest and its public service provider BKV occupy top position in the field of passenger traffic data in relation to the examined cities. This is particularly noteworthy in light of the fact that the level of external funding (compensation) is below average. In general, the share of rail-bound sectors does not seem to be significant in terms of line length, but it should also be taken into account that their share place kilometres and number of passengers carried is much more intensive.

It is unfortunate that based on 2017-2018 data BKV has the oldest average-age bus, trolleybus and tram fleet among the examined cities, and this is not compensated by the fact that the youngest fleet of underground vehicles operates in Budapest. Vienna (3 years) for buses, Bratislava (5.9 years) for trolleybuses and Prague (11.14 years) for trams hold the youngest fleet. The aging vehicle fleet poses increasing operational safety risks and is also detrimental to the attractiveness of public transport.

It is similarly unfavourable for Budapest that, despite the noticeably improving trend in recent years, it has not been possible to reach the 100% level in the field of buses in the proportion of low-floor vehicles (as in Vienna or Warsaw), and in the case of the tram sector, the share of low-floor vehicles is the worst (16.7%) for the studied capitals. From a social point of view, it is essential that this ratio be improved as part of the availability of public transport.

In terms of modal split values, Budapest showed the highest public transport rate (48%) in terms of the cities surveyed, which is favourable and needs to be strengthened to be liveable and sustainable on the long term. The favourable situation in Vienna is indicated by the lowest rate of car use (27%), at the same time, the share of bicycles (7%) and pedestrian traffic (27%!!!) is the highest among the studied capitals, which is worth considering as a goal in the long-term development of Budapest.

As an important additional element in the development of public transport, it can be stated that while Budapest, Prague and Warsaw have several smaller capacity P+R facilities, Vienna is more characterised by a smaller number of large-capacity (typically one-thousand-space) parking garages and underground garages.

Based on the above, I consider my first two hypotheses justified and make the following findings:

In Budapest one of the most significant turning points of the regional approach to road railway can be attributed to the change of regime, which has led to a broadening of the regional approach to public transport, while in the field of transport services, the paradigm shift that took place as a result of the regime change also forced a Fordist-post-Fordist transformation. The transport management tasks of the capitals of the V4 countries and Austria generally appear separately from the transport service and the city, and the transport needs of the agglomeration are typically assessed and met from a regional perspective. The regional, co-evolutionary transport and urban development typical for Budapest does not prevail in the field of transport organisation within the capital. In regional comparison, the Budapest public transport system can be characterised by a high average age of the operated equipment.

4.2. Conclusions of the examinations relating to excessive operation and efficiency improvements of trams

Public transport can be a good tool for tackling a number of problems affecting cities (mobility, pollution, urban development, transport traffic), which are also reflected in the fundamental social, economic and environmental expectations of the system. Given that there is no uniform definition for a sustainable transport system, significant differences and shifts in emphasis can also be identified in the relevant literature regarding the expectations and approaches to the transport system. Based on the processing of literature dealing with the impact of each vehicle type and mode of transport on the social, economic and natural environment, I arrived at the conclusion that of the surface public transport modes, road railway satisfies the need for the balance of the environment and society the most, supporting the development of cities as well, so depending on the financing possibilities, it is justified to give priority to this means of transport and increase its efficiency. Like several major cities in the world, Budapest, as well as major Hungarian cities with road railway equipment and infrastructure, has an aging rolling stock of trams, operating beyond its useful life (typically 30 years). Accordingly, in my dissertation, focusing on the main issues of excessive operation of trams, I sought the answer the following questions:

- What is the relationship between excessive operation of trams and failures, costs, and accidents?
- What operational options are available to increase the efficiency of road railway?
- What is the practice pursued by the domestic public transport service providers with road railway equipment and infrastructure in respect of the management of operation beyond the useful life?

4.2.1. Main conclusions of the correlation examination

The purpose of the context study on excessive operation is to support the relevant decision-making processes by presenting the impacts of excessive operation. In the context of the correlation analysis (failures and costs) I analysed the effects of ‘excessive operation’ of electric vehicles in two dimensions (mileage and elapsed time), which, in theory, can themselves correlate with cost and error rates, as this is considered natural at the end of the planned service life.

In the event that costs, and failures do not increase significantly during operation beyond the planned service life, it is possible to change the cycles, which can lead to significant cost savings. Otherwise, if the failures and costs show an upward trend even within the planned service life, it may be necessary to tighten maintenance activity. With regard to examining the correlation of costs, the increase in personnel costs of maintenance is also influenced by wage increase, however, in our case, this is significant only in the last 3 years (above 10% in 2017-2019), while in the period between 2010-2016 it was only between 1-3%. Some of the repairs of higher maintenance cycles, – the 'J' repairs –are carried out by an external contractor (VJSZ), therefore some of the personnel costs are limited to preparation and to putting into service

The operation of the equipment, including vehicles, in terms of technical approach and reliability, can be described as a bathtub curve. This means that after their production, they are characterised by a relatively high degree of failure for a short period of time, which errors are mainly due to manufacturing inaccuracies (assembly faults). This period is followed by a long, good period of reliability where the error rates become constant with no abrupt changes experienced. In the last phase of operation, failure rates begin to rise again, which is a good indication of the need for replacement or refurbishment.

The main correlations revealed by the examination can be interpreted as follows:

- One of the important conclusions of the examination is that M2 error is not affected by mileage, which can be explained by distinguishing between two error types (M1-M2). Fault M2 has a more significant effect than M1, since then the vehicle will not remain in service but will be replaced. In modern operating practice, operators are afraid not of errors, but of errors with consequences! The high number of faults that can be easily repaired during maintenance without other consequences can also mean that the given part or equipment has been used up to the limit of its operability, i.e. 100% of its potential has been used. From the low number of M2 faults, which are independent of mileage, it can be concluded that the operation is cost effective. No intervention is recommended!
- There is already a strong correlation between M1 errors and mileage for some models, which was supported by the analysis performed for vehicles types IA (industrial articulated), UIA and TW6000. The close correlation

between the high age and failure rates of IA and UIA trams and mileage could be a good reason for them to be among the first ones to be replaced as far as possible. The main reason for their operation stems from their geometric and mass characteristics, as they are narrow and 'light' trams that can be operated in places where modern, high-capacity (wide and heavy) vehicles may not travel. Therefore, it can be concluded that, although their number is not decisive, it is worthwhile to carry out further technical analyses in order to establish the specific reason for the strong correlation between mileage and the number of failures, as is recommended for TW6000s.

- In higher cycle examinations, typically the tasks with higher cost are performed, following higher mileage. The purpose of separating material and personnel costs is to establish the origin of a potential close correlation. As regards the types with strong correlation coefficient identified in the examination, all refer to personnel costs except for the IA in 2006. It can be seen from the diagrams that the increase in personnel costs is related to mileage, from which we can conclude that this may also result from increased working hours and wage increases. As the previous reasons point toward deterioration in efficiency, it is recommended to intervene in the process!
- Given that the investigation showed that the cost of material was insignificantly affected by the number of defects, it can be concluded that few materials were needed to correct them. It follows that the increase in personnel costs of maintenance was also affected by increased working hours. The few and weak correlations can be explained by the fact that troubleshooting is typically performed during daily maintenance and does not affect higher-cycle examinations. If this changes, a review of daily maintenance is required.
- Based on the findings of the examination, the T5C5K can be said to produce few failures even beyond their planned service life. From this result it can be concluded that the further operation of this type is expedient and significant cost savings can be achieved by reviewing or modifying its cycles.
- In the case of UIA trams, in 2008 (at the age of 38) the M2 error numbers were around 25 errors per vehicle. It was exceeded in one case, in 2013 (at the age of 43) amounting to 6 cases out of 30 vehicles, while at the age

of 50, in 2019, the error rates for all vehicles remained below 19! The improvement should clearly be interpreted as the effect of higher-cycle repairs, the composition and cost implications of which need to be considered.

- In the case of IA cars, we can conclude from the increase in material costs that the vehicle is nearing the end of its lifecycle. In order to avoid significant expenses, it is advisable to replace them as soon as possible.

During the examination, I identified a significant relationship between the excessive operation of trams and the failures and costs, but these were not related to the planned lifecycle. Among the correlations examined, the results related to accidents show that the correlation between excessive operation and the increase in the number of accidents cannot be justified, which can be considered perhaps the main finding of the dissertation.

Considering all this, it can be stated that the planned life-time specified by the manufacturer does not represent a mandatory expiration date from the aspect of the use of the given equipment, this way it opens a new opportunity to operators to reconsider the maintenance cycles (which may result in significant cost reductions, too), and, respectively, in Budapest the number of accidents is independent from excessive operation.

On the basis of these, my third hypothesis is justified.

4.2.2. Main conclusions of the optimisation examination

Exploring the options of optimising operation in the life of companies operating large systems is an ongoing task. There are trivial or seemingly trivial options and hidden reserves, the exploration of which can sometimes originate from a new approach or can even be the result of chance. Timetable optimisation software solutions have been used for a long time in the field of transport services, but the opinions of service providers differ on their effectiveness (5-15%). What is certain: in our days advanced computers and intelligent software solutions can significantly support the study of more complex mathematical correlations. In my dissertation, I presented the potential and limitations of timetable optimisation, mature by now, as an example, and I also highlighted a new possibility that analyses the savings potential of daily car release.

The optimisation option I have described can be seen in rethinking of car release, which favours vehicles that can be operated at lower cost according to the daily timetables. Budapest's resources have never been unlimited, and on the portion that can be spent on public transport it can be said that in the last two or three decades, it has typically been enough for half or a third of what would be justified. Due to the above, it is justified to introduce a 'realistic' approach during a tram performance optimisation task, which could provide an opportunity for implementation. Given that actual performance data, availability, and infrastructure constraints are also known, it can be examined whether the vehicle composition used (car release) is optimal in terms of cost utilisation. The examination presents a theoretical model, which minimises all costs through mathematical calculation based solely on the narrowed direct costs per type, including capturing a point in time (even if it is the average of several years), using a static state based on its magnitude. This was essentially the aim of the model, but the actual feasibility and realisation of cost savings is influenced by a much more complex set of criteria. In terms of costs, in order to be able to produce the model, the cost level used for the analysis basically relied on the data of one year (2018), but correcting the effect of the momentary maintenance and maintenance tasks, adjusted with the average of several years. To calculate the minimum model, this calculation is initially appropriate, provided that if a real decision is made based on the theoretical model, it will be necessary to examine the actual influencing factors beforehand. In conclusion, the conceptual model is suitable – and this is a very important factor in increasing efficiency and optimisation – to find decision points and opportunities.

Taking all this into account, the results of the optimisation confirmed my fourth hypothesis, according to which, even with the excessive operation of trams, a car release scheme can be established in the daily timetable of trams, resulting in cost savings and increased efficiency.

4.2.3. Main conclusions of the examination of the domestic practice of excessive operation

Based on the conducted interviews it can be stated that the useful life of the operated assets is determined according to different methodology. In Budapest, Miskolc, and Debrecen the consideration of the manufacturer's recommendations is the decisive factor in determining the useful life of the equipment, while in

Szeged it is only influenced by accounting expectations. In view of the technical possibilities and needs, the applied methodology is currently under review in Szeged, the assets are expected to be re-evaluated in the future, and the manufacturer's recommendations will be considered here as well. In my opinion, the planned useful life of technical equipment and devices is basically a technical issue and it is essential to take into account the manufacturer's recommendations. When making decisions on operation beyond the useful life, BKV follows a validated methodology, where decisions are made at management level after professional preparation. By contrast, in rural cities these decisions are made by the operators, which in my opinion is not sufficient to implement a unified corporate strategy. There is a significant difference in the practice of risk management in relation to Budapest and rural cities, as we can find two-tier risk management only in the case of BKV. In the practice of BKV, in addition to the legal requirements, a unified system is also operated that takes into account the goals of the company and gives priority to the management of excessive operation, which in my view is justified. In my opinion, it is reassuring that in all the cities examined the recording of additional costs incurred in connection with further operation is adequate, but only at BKV can the foundations of lifecycle cost management be identified, the development and completion of which is yet to come. I also found a discrepancy in the analysed systems regarding accounting, whereas, except for Budapest, revaluations are carried out only during technical interventions that increase lifecycle. If a technical rating like the TPP were also treated as an option for reassessment, more reliable company data would emerge, which could help specify the objectives.

Based on the above, my fifth hypothesis, i.e. that despite the fact that of the domestic public transport service providers with road railway vehicle fleet and infrastructure only BKV has a declared, science-based methodology developed for the purpose of operation beyond the useful life, the examination of the technical and risk aspects of the excessive operation of trams is an integral part of the practice of all public transport providers – is acceptable. It should be noted, however, that a two-tier system of risk management and a protocol on further operation with scientific demand could greatly improve the safety and economic indicators of the specific company.

5. SUMMARY OF THE NEW SCIENTIFIC RESULTS

The new scientific results of my dissertation can be summarised the following way:

1. In a unique way, I carried out the identification of the regional, historical periods of road railway in Budapest by defining their turning points.

   A comprehensive, systematic, and at the same time, gap-filling work was produced, which helps to interpret the importance of regionalism in relation to public transport. Through the examples of BKV and road railways, I highlighted the main dimensions and the most defining challenges of the issue.

2. In my dissertation, I summarised the social, economic and environmental impacts of urban public transport modes, in the framework of which I highlighted the contradictions between people's need for mobility and the protection of the environment.

   By including the issue of further operation in the scope of the analyses, I found another point of view in the tools of problem interpretation, which facilitates a more accurate understanding and management of negative effects.

3. During the examination of the operating conditions of the transport providers operating in the capitals of the V4 countries and Austria I identified differences that explain the existence of obsolete equipment and the results of the passenger satisfaction surveys.

   The underfunding of Budapest, the aged equipment and the limited activity of the transport organizer within the city boundaries in any case justify changes, which have been substantiated on the basis of good examples and my research.

4. In the course of my analyses, I discovered a new optimisation option in the field of car release which can be used to reduce operating costs.

   By re-thinking the attempts to increase efficiency related only to timetables so far, I managed to incorporate a hitherto unexplored possibility into the planning of car release, which can result in significant cost reduction.

5. Through my research, I found correlation between the excessive operation of trams and their failures and costs, and I also identified the weaknesses of the manufacturer's specifications for the planned service life.

   The importance of the new approach is enormous in terms of making vehicle maintenance more cost-effective, as vehicle maintenance and the relevant cycles have become more precisely definable, facilitating much more reliable and economical operation.

6. PUBLICATIONS ON THE TOPIC OF THE DISSERTATION

Articles in periodicals:

1. **TAKÁCS P.** (2020): Operating Urban Public Transport Rail Infrastructure and Vehicles Over Planned Life Cycle and Its Economic Aspects within the Company (analysis and fine-tuning of the science based continued operation protocol (SCOP) decision support model). *Studia Mundi – Economica*, 7 (2), p. 65-78, HU ISSN 2415-9395, MTMT number:31348181
2. **TAKÁCS P.** (2020): Theoretical optimisation of tram availability for daily schedules (role of public transport and trams in Budapest). *Studia Mundi – Economica*, 7 (3), p. 86-96., HU ISSN 2415-9395, MTMT number: 31598389
3. BENCZŐ L., TÓTH T., **TAKÁCS P.,** BARANYAI G. (2020): A vállalati napenergia termelés feltételrendszere. (Conditions for corporate solar energy production.) *Studia Mundi – Economica*, 7 (4), p. 24-33., HU ISSN 2415-9395, MTMT number: 31621132
4. BENCZŐ L., TÓTH T., **TAKÁCS P.,** BARANYAI G. (2020): Mi lehet a háttérben? Van valami a háttérben? (What could be in the background? Is there something in the background?) *Studia Mundi – Economica*, 7 (4), p. 16-23., HU ISSN 2415-9395, MTMT number: 31621114
5. **TAKÁCS P.** (2019): A közösségi közlekedés helye és szerepe Európa városaiban. (The place and role of public transport in European cities.) *Közlekedéstudományi Szemle*, 69 (4), p.17-32., DOI: 10.24228/KTSZ.2019.4.2, MTMT number: 30778029
6. **TAKÁCS P.**, KOZMA Á (2018): Vaskerekes ágazatok az 50 éves BKV-ban – A gördülőállomány 50 éve. (Iron-wheeled sectors in 50-year-old BKV – 50 years of rolling stock.) *Városi Közlekedés,* 8 (4), p.16-23, HU ISSN 0133-0314, MTMT number: 30787500
7. FIÁTH A., NAGY V., **TAKÁCS P**., BALOGH L., BÁLINT Á., NAGY B., DINYA M. (2016): A közlekedési eszközpark és infrastruktúra hasznos élettartamát tudományos alapon növelő technológia kidolgozása a BKV Zrt. számára. (Development of technology for BKV Zrt. to increase the useful life of transport equipment and infrastructure on a scientific basis.) *Vezetéstudomány*, 47 (3), p. 2-11., ISSN 0133-0179, MTMT number: 30787367

8. **TAKÁCS P.** (2011): Budapest integrates new elements in its public transport services. *Eurotransport* (The paper has been renamed, new name: Intelligent Transport, ISSN1478-8217), 6/2011, p.13-15., MTMT number: 30787474
9. **TAKÁCS P.** (2010): A budapesti metró múltja, jelene, jövője – a jelenlegi műszaki háttér, fejlesztések, tervek. (The past, present and future of the Budapest metro – the current technical background, developments, plans.) *Városi Közlekedés*, 1 (6), p.333-337., (HU ISSN 0133-0314), MTMT number: 30787407
10. **TAKÁCS P.** (2009): The complex reconstruction of Budapest Metro Line 2; *Eurotransport* (The paper has been renamed to Intelligent Transport, ISSN1478-8217), 6/2009, p.18-24, MTMT number:30787431

Conference lectures, studies published in conference volumes

1. **TAKÁCS P.** (2020): *The service performance optimization potentials of the tram branch of BKV Zrt. (goals and key elements of a service optimization model)*, In: Horváth B., Horváth G. (szerk.): X. Közlekedéstudományi Konferencia 2020. Győr (Tanulmánykötet), Győr, Magyarország: Széchenyi István Egyetem Közlekedési Tanszék, KözlekedéstudományiEgyesület (2020), p65-72, ISBN 978-963-8121-89-9, MTMT szám: 31777322
2. **TAKÁCS P.** (2020): *The service performance optimization potentials of the tram branch of BKV Zrt. (goals and key elements of a service optimization model)*, In: Horváth B., Horváth G. (szerk.): X. Közlekedéstudományi Konferencia 2020. Győr (Tanulmánykötet), Győr, Magyarország: Széchenyi István Egyetem Közlekedési Tanszék, KözlekedéstudományiEgyesület (2020), p52, ISBN 978-963-8121-88-2, MTMT szám: 31777245
3. **TAKÁCS P.** (2020): *Városi közlekedés és a környezet (a városi vasutak jelentősége)*. [Urban transport and the environment (importance of urban railways).] In: Nagy, L. (Ed.): *City Rail 2020 Conference*. Budapest: Budapesti Közlekedési Vállalat Zrt., Scientific Association for Transportation (Hungarian abbreviation KTE), pp. 10-18., City Rail 2020 Conference, Budapest, 15.10.2020, ISBN 978-963-8121-90-5, MTMT number: 31318256,
4. **TAKÁCS P.** (2020): *Indicators of Hungarian cities operating urban rail networks, analysis of correlations of place kilometre data of transport companies (Economic and social correlations of transport development in*

Budapest). In: Horváth, B., Földi, P., Kápolnai, Zs. (Eds.): *VI. Winter Conference of Economic PhD Students and Researchers: Conference Proceedings*. Budapest: Association of Hungarian PhD and DLA Students, p. 223-231, ISBN 978-963-269-914-1, MTMT number: 31629004

5. **TAKÁCS P.** (2020): *Indicators of Hungarian cities operating urban rail networks, analysis of correlations of place kilometre data of transport companies (Economic and social correlations of transport development in Budapest)*. In: Horváth, B., Földi, P., Kápolnai, Zs. (Eds.): *VI. Winter Conference of Economic PhD Students and Researchers, Book of Abstract*. Gödöllő: Szent István University, Association of Hungarian PhD and DLA Candidates, Department of Economics, p. 120, ISBN 978-963-269-895-3, MTMT number: 31198348
6. **TAKÁCS P.** (2019): *The role of public transportation in economic development*. In: Horváth B., Földi P., Kápolnai Zs., Antalík I. (Eds.): *International Conference of Economics PhD Students and Researchers in Komárno, Book of Abstracts*. Komarno: János Selye University, p.30., International Conference of Economics PhD Students and Researchers in Komárno, 5th of November, 2019; ISBN 978-80-8122-334-1, MTMT number: 31137172,
7. **TAKÁCS P.** (2019): *Description of the Fordist – Post-Fordist transformation of Budapest Transport Company (BKV) through its strategic elements*. In: Horváth B., Földi P., Kápolnai Zs., Antalík I. (Eds.): *International Conference of Economics PhD Students and Researchers in Komarno: Conference Proceedings*, Komarno: János Selye University, p.178-190, International Conference of Economics PhD Students and Researchers in Komárno, 5th of November 2019, ISBN 978-80-8122-348-8, MTMT number: 31318301
8. NAGY V., BOZÓKY L., **TAKÁCS P**., LUKÁCS S. (2019): *Városi kötöttpályás jármű gumirugós kerék abroncselfordulás elleni biztonságának növelése* (Increasing the anti-rotation safety of a rubber spring wheel tire in an urban rail-bound vehicle). In: Szabó A. (Ed.): *Tanulmányok a vasúti járművek és a jármű-rendszer-analízis témaköreiből 2019 – Emlékkönyv Prof. Dr. Zobory István 75. születésnapja alkalmából* (Studies on the topics of railway vehicles and vehicle system analysis 2019 – Memorial book on the occasion of Prof. Dr. István Zobory's 75th birthday), Budapest: BME ITS Nonprofit Zrt., p.140-143., ISBN 978-963-313-343-9, MTMT number: 30804870

9. DÖME B., NAGY V., ORBÁN T., **TAKÁCS P.** (2019): *Kötöttpályás egyetemes járműfenntartás stratégiai célú rendszermodell*. (Rail-bound universal vehicle maintenance is a system model for strategic purposes.) In: Szabó A. (Ed.): *Tanulmányok a vasúti járművek és a jármű-rendszer-analízis témaköreiből 2019 – Emlékkönyv Prof. Dr. Zobory István 75. születésnapja alkalmából* (Studies on the topics of railway vehicles and vehicle system analysis 2019 – Memorial book on the occasion of Prof. Dr. István Zobory's 75th birthday), Budapest: BME ITS Nonprofit Zrt., p.132-139., ISBN 978-963-313-343-9, MTMT number: 30804888
10. **TAKÁCS P.** (2019): *Vasúti járművek és infrastruktúra elemek üzemeltetési kérdéseinek, illetve ezek műszaki és gazdasági hatásainak vizsgálata*. (Examination of the operational issues of railway vehicles and infrastructure elements and their technical and economic effects.) In: Horváth G., Gaál B., Horváth B. (Eds.): *Közlekedéstudományi Konferencia Győr 2019 Conference on Transport Sciences: Alternatív-Autonóm-Kooperatív-Komparatív Mobilitás:* (Alternative-Autonomous-Cooperative-Comparative Mobility:) Volume of abstracts. Győr: Széchenyi István University, p. 121., Conference on Transport Sciences Győr 2019.03.21-22, MTMT number: 30778085
11. **TAKÁCS P.** (2019): *Vasúti járművek és infrastruktúra elemek üzemeltetési kérdéseinek, illetve ezek műszaki és gazdasági hatásainak vizsgálata*. (Examination of the operational issues of railway vehicles and infrastructure elements and their technical and economic effects.) In: Horváth G., Gaál B., Horváth B. (Eds.): *Közlekedéstudományi Konferencia Győr 2019 Conference on Transport Sciences: Alternatív-Autonóm-Kooperatív-Komparatív Mobilitás:* (Alternative-Autonomous-Cooperative-Comparative Mobility:) *Study volume*. Győr: Széchenyi István Egyetem. paper 76 (p. 12). Conference on Transport Sciences Győr 2019.03.21-22, MTMT number: 30787325

7. LITERATURE

1. AUVINEN, H., TUOMINEN, A. (2014): Future transport systems: long-term visions and socio-technical transitions. *European Transport Research Review*, 6 (3), pp. 343-354
2. BELUSZKY P. (1973): Adalékok a magyar településhierarchia változásaihoz 1900–1970. (Additions to the changes in the Hungarian settlement hierarchy 1900–1970.) *Földrajzi Értesítő*, 22 (1), pp. 121–142
3. BKK (2014): Balázs Mór Plan: Budapest Transport Development Strategy 2014-2030. https://bkk.hu/wp-content/uploads/2014/06/BMT.pdf. Search engine: Google. Keywords: Transport development plan. Query date: 13.09.2019
4. ENYEDI GY. (1997): A sikeres város. (The successful city.) *Tér és Társadalom*, 11(4), pp. 1-7
5. ENYEDI GY. (2011): A városnövekedés szakaszai – újragondolva. (Stages of urban growth – rethought.) *Tér és Társadalom*, 25 (1), pp. 5-19
6. EUROPEAN COMMISSION (2009): Indicators to Assess Sustainability of Transport Activities. http://publications.jrc.ec.europa.eu/repository/bitstream/JRC54971/sust_transp_ind_report_final.pdf. Search engine: Google. Keywords: Sustainability Transport. European Union. Search engine: Google. Keywords: Sustainable city. EU. Query date: 08.06.2020
7. FIÁTH A., NAGY V., TAKÁCS P., BALOGH L., BÁLINT Á., NAGY B., DINYA M. (2016): A közlekedési eszközpark és infrastruktúra hasznos élettartamát tudományos alapon növelő technológia kidolgozása a BKV Zrt. számára. (Development of technology for BKV Zrt. to increase the useful life of transport equipment and infrastructure on a scientific basis.) *Vezetéstudomány,* 47 (3), pp. 2-11
8. GEELS, F. W. (2005): The dynamics of transitions in socio-technical systems: a multi-level analysis of the transition pathway from horse-drawn carriages to automobiles (1860–1930). *Technology analysis & Strategic Management,* 17 (4), pp. 445-476

9. HADJILAMBRINOS, C. (1998): Technological regimes: an analytical framework for the evaluation of technological systems. *Technology in society*, 20 (2), pp. 179-194
10. HALL, R. P. (2009): Understanding and Applying the Concept of Sustainable Development to Transportation Planning and Decision-Making in the U.S. PhD Thesis. MIT, p.872 https://dspace.mit.edu/handle/1721.1/34555. Search engine: Google. Keywords: transportation. Sustainability. Query date: 16.08.2020
11. JANKÓ D. (2019): A fenntartható városi mobilitási tervek mellett, közúti közlekedésbiztonsági akcióprogramokra is szükség van. (In addition to sustainable urban mobility plans, road safety action programmes are also needed.) *Városi közlekedés*, 4 (4), pp. 4-11
12. KAIJSER, A. (2005): How to describe large technical systems and their changes over time? pp. 12-19 In: Jönson, G., Tengström, E. (Eds.): *Urban Transport Development*. Berlin: Springer. p. 301
13. KÁPOSZTA J. (2018): A jó kormányzás regionális összefüggései a vidéki térben. (Regional contexts of good governance in rural areas.) *Studia Mundi-Economica*, 5 (3), pp. 70-78
14. KOVÁCS Z. (2017): Városok és urbanizációs kihívások Magyarországon. (Cities and urbanisation challenges in Hungary.) *Magyar Tudomány*, 178 (3), pp. 302-310
15. MILLER, P., DE BARROS, A.G., KATTAN, L., WIRASINGHE, S.C. (2016): Analyzing the sustainability performance of public transit. *Transportation Research Part D*, 44, pp. 177–198
16. OTTENS, M., FRANSSEN, M., KROES, P., VAN DE POEL, I. (2006): Modelling infrastructures as sociotechnical systems. *International Journal of Critical Infrastructures*, 2 (2-3), pp. 133-145
17. UNITED NATIONS (2020): https://population.un.org/wup/Download/. Search engine: Google. Keywords: Population. Query date: 16.05.2020