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1. WORK ANTECEDENTS, OBJECTIVES SET

Public transport is one of the pillars of sustainable life in cities: its development is crucial for the livability, further development of cities and the quality of life of people (Mees 2000, Lucas 2006, Welch–Mishra 2013, Eboli–Mazzulla 2015). The creation of new transport routes can offer new access alternatives, but there may also be physical and financial constraints to expansion. The main objective is to increase the number of passengers – which is only possible with public transport satisfaction – and at the same time reduce the share of people choosing individual means of transport (Beirão–Cabral 2007, Carreira et al. 2013, Ramos et al. 2019). However, this requires an assessment of the preferences that lead people to choose public transport. It is necessary to know exactly which factors are the most important criteria determining the choice of the mode of transport, i.e. improving satisfaction with public transport and developing sustainable urban transport has become one of the most important priorities in urban development. (De Oña et al. 2016).

My professional interest in the topic partly stems from the fact that as a member of the staff of one of the key players in the public transport system of the capital, I am confronted with the public's feedback on the quality of the transport infrastructure on a daily basis. The other reason is my personal interest in public transport equipment, especially vehicles, during the procurement of which the operator should also consider the previous feedback from passengers, which are professionally feasible.

The aim of writing my doctoral dissertation was to understand the methodologies for measuring quality in the transport sector, to understand the preferences of the service users' group through qualitative research, and to develop a novel methodology for a more accurate quantitative indicator of service quality in order to achieve the European Union's objectives of increasing the share of public transport and reducing the number and severity of road accidents, based on international and national practice. By an approach that takes into account the specificities of each municipality, a more sophisticated measurement system can be created in the survey methodology than the current one.

1.1. Topicality, relevance and delimitation of the subject

Increasing the modal share of public transport within all kinds of transport is inevitable to promote sustainable development (Erdősi 2002, Gyulai 2013, Káposzta-Tóth 2023). Part of this is the assessment of operators, and although the market is still only partially open, knowing the preferences of the travelling public is not only a huge advantage for the operator in a competitive situation, but also a key factor in the sector's ongoing "battle" against private transport.

The current practice in Budapest is that the passenger's experience of the quality and condition of the transport system (vehicles and built infrastructure), punctuality of the timetable and transport safety is related to the operator's activity. It is important, therefore, that all members of the public transport institutional system receive feedback from both the practical and potential target groups of the service through information on travel preferences, so that the customer and the operator can make decisions within their own competence and formulate development directions, which, if implemented, will provide a systemic advantage for public transport over private transport – in line with the sustainability objectives of the European Union.

As a result of technological progress, new vehicles are more complex than the old ones they are replacing: the low-floor design entails a number of structural compromises, and meeting the naturally increasing demands of passengers requires the integration of more and more subsystems on-board.

More complex vehicles therefore use more modern technologies and materials, which are necessarily more expensive to repair or replace. Therefore, it is (also) particularly important to analyse the accident data of newer, high-value vehicles in real operational environments, to determine how the urban structure of a given local area influences the accident data of public transport through the determined design of traffic routes.

The EU's objective is to reduce the number of fatalities and serious injuries in road accidents by 50% by 2030, and to reach a "Zero Vision" target of zero fatalities in road accidents by 2050 (Winkler–Henezi 2023).

The evaluation of accident data for a given period of time for a specific transport subnetwork can provide a good starting point for a quantitative type of analysis, as a result of which I would like to investigate the impact of new vehicles to be put into operation on primary transport safety.

My investigation is limited, from among the asset groups operated by BKV Zrt., to trams. This is due to the specificities of bus and metro as the other two sectors with relevantly high traffic performance and thus meaningful comparability.

1.2. Objectives, research questions and hypotheses of the thesis

The research objectives, the questions and hypotheses formulated in relation to them are summarised in Table 1:

Table 1: RESEARCH OBJECTIVES, QUESTIONS AND HYPOTHESES

Research			
	objectives	**questions**	**hypotheses**
1.	I will investigate the priorities on the basis of which the users of the public transport network in the local area evaluate the service.	Which passenger satisfaction components contribute to increasing the share of public transport users compared to private motorised transport?	Journey time optimisation is a high priority attribute of passenger satisfaction.
2.	I analyse the territorial disparities in the transport network in a given urban structure in terms of the transport safety component affecting the level of service.	Looking at the tram network in Budapest, which territorial characteristic can be identified that has a negative impact on service quality?	The endowments of urban structure and traffic management on transport routes have an impact on the development of a specific indicator of service quality.
3.	I evaluate how a new technological element in a specific transport system affects the safety aspect of service quality.	How does a new public transport technology in a local area affect the safety component of service quality?	The introduction of a new type of public transport vehicle in a given local area reduces the number of accidents on that network.
4.	I examine the transport safety impact of the human resource management of a transport service in a given spatial structure.	What is the impact of the professional qualifications of those directly involved in the service on the measurable quality of the public transport service in the local area?	The number of internal fault and external fault accidents for public transport operators in the local area is influenced by the assignment of human resources based on their time of experience.

Source: edited by the author (2024)

2. MATERIAL AND METHODOLOGY

2.1. Structure and test methods of the thesis

In order to understand the methods for evaluating the quality of public transport services, I examined the relevant international and national literature on the subject. At the beginning of my overview, I presented the processes of urban development and transport development, the parallels that can be identified, that changes in the transport system have an impact on the development of the economic activity of a given territorial unit and thus on urbanisation processes. However, at the same time, it can be concluded that the development of a given local area has an impact on the development of the transport system itself.

I have identified the distinctive elements of Budapest's urban development, which, by placing them in a historical context, have led to a set of conclusions that can be applied to transport. I then investigated the relationship between urbanisation and changes in mobility needs, showing the increase in the share of private transport in relation to urbanisation. I also detailed the role and importance of transport in the economy, the impact of public transport on the GDP of a region, how it serves to reduce territorial disparities, the added benefits of public transport to a given region and, finally, I pointed out the link between transport development and regional development, using national references. I explained how transport is linked to the EU's sustainable development goals and, within that, how public transport serves the EU's sustainability objectives.

Then I analysed the relationship between transport safety and public transport based on national and international examples, highlighting the importance of the fact that transport safety has a decisive influence on passenger satisfaction. I discuss the political background of transport: the EU and national aspects, which together define the operational framework and the development directions of the transport sector. I presented the transport endowments in Budapest from a spatial and historical perspective, giving an insight into the organisational and institutional structure of the different eras of public transport, which can be distinguished by their specific characteristics, and, based on the data and literature references presented, I have made a brief summary proposal for comparing the socio-technical and transport characteristics of each era.

Through a general definition of public services, I also presented the public services of transport, which I considered important to include in order to describe the operating environment and the role of service quality within the institutional system. I also looked at the concept of quality, its relationship with satisfaction and its role in public transport: I reviewed the main literature on the subject.

Finally, I presented the key databases and research methodologies that I used to assess the quality of public transport from two directions: on the one hand, I evaluated primary information collected through a questionnaire survey together with my fellow researchers, and on the other hand, I analysed secondary information in detail through a quantitative study by analysing a factor that is decisive for the assessment of service quality, the transport safety indicator.

On the basis of my research results and hypotheses I have drawn conclusions and formulated recommendations that can be put into practice, which I conclude with a summary in Hungarian and English.

The research I have carried out is essentially of an applied research nature, because, in line with my research objectives, I have proposed significant improvements to existing procedures and services based on new or novel contexts and knowledge that are of practical use. In my research,

I drew conclusions and formulated results from the databases created using mathematical and statistical methods.

The conceptual design of my research and the methodology used are presented in Figure 1.

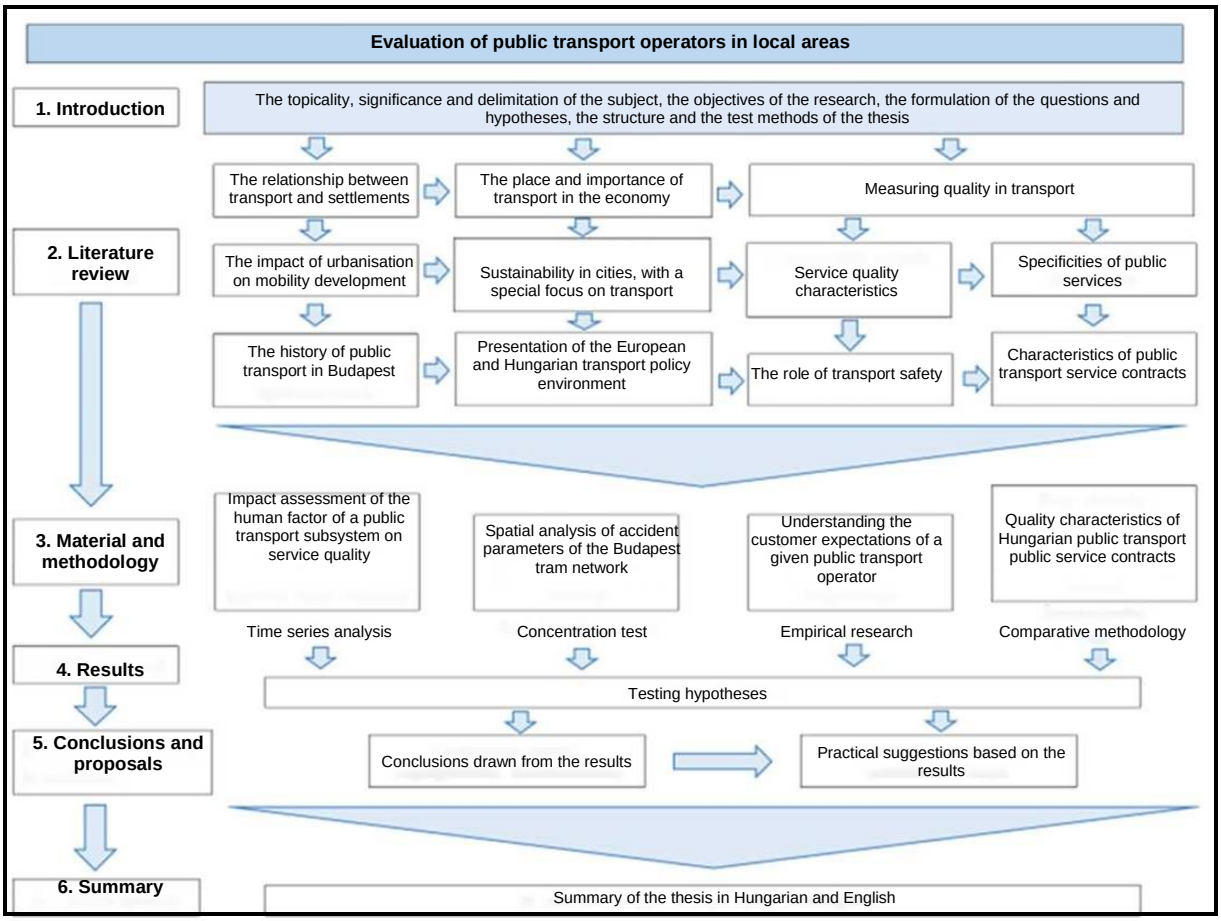

FIGURE 1: STRUCTURE OF THE DISSERTATION

Source: edited by the author (2024)

2.2. Evaluation of public transport

Improving the service quality has been shown to play a key role in encouraging car users to switch to public transport and, as a result, reduce the pollution caused by transport (Transportation Research Board 1999). By assessing passengers' preferences, the spotlight can be put on intervention points where satisfaction can be increased with "minimal" effort. Safety is one of the most important factors that influence satisfaction with public transport (Stradling et al. 2007, Barabino et al. 2021) and has a significant impact on the number of passengers (Delbosc–Currie 2012). Only 10% of people would consider using public transport if they did not feel safe (Crime Concern 2002). As a result, the less safe people feel public transport is, the more likely they are not to use it. (Lynch-Atkins 1988).

There are basically two approaches to safety: one is the degree to which passengers feel safe during the journey. In terms of these indicators, public transport is a relatively safe option for passengers. (Cafiso et al. 2013; Nordfjærn-Rundmo 2010; Truong-Currie 2019). The other factor, however, is much more elusive and varies in strength from one individual to another: real or perceived fear of assault, theft, physical atrocity, verbal conflict that may occur during the journey. My dissertation focuses on security in the first sense, although both are extremely important (Fellesson–Friman 2012; Spears et al. 2013; Stuart et al. 2000; van Lierop et al. 2017; Allen et al. 2018b; Guirao et al. 2016; Figler et al. 2011; Nathanail 2008; Shiwakoti et al. 2019), the factor I study is the attribute that can be influenced by the operator. Furthermore, much of the research shows that from these two this one is more important for users and potential users (de Oña et al. 2021).
In a separate assessment of each area – passenger information, reliability, employees, speed, etc. – the Budapest 2020 customer survey gave safety a score of 80.3 out of 100. In terms of weighting, it scored the highest at 8.7, alongside reliability and accessibility. Passengers rated the vehicles mainly in terms of accident risk, with metro (85), suburban train (83) and tram (82) being the safest, while bus (80) and trolleybus (80) were considered the least safe (BKK 2020).
The main conclusion of international research on the subject is that the travelling public could be increased if the level of service demanded by passengers was provided. Studies on the perception of travel time have highlighted the importance of direct travel, as transfers tend to have a negative impact on overall travel satisfaction (De Abreu e Silva and Bazrafshan 2013), thereby reducing travel demand (Lythgoe and Wardman 2002).

2.3. Methodologies used in my analysis

In my dissertation I use several methodologies, as I could get at the different types of data with different methods. By the online assessment of the passengers, on the one hand, I wanted to prove the justification of the quality criteria required by the transport organizer in the public service contract, and on the other hand, by bringing out the issue of safety, I prepared my other major scope of examination.

First, I describe the methodologies used in literature.

The research methods can be of two types: primer or seconder researches. In the former case the research objective is collecting and analysing specific, first-hand information. These can be qualitative or quantitative surveys, including experiments, questionnaire surveys, interviews. In the latter method, the data to be processed derives from other sources, usually they are recorded with no research purposes.

In primer surveys basically two methods are used, depending on whether the research objectives can be achieved by qualitative or quantitative methods, or by the combination of the two.

Quantitative surveys are mostly deductive, the target of information collecting is to prove the hypotheses and the outlined theoretical statements. Mathematic-statistic methods are used at this research type, and the results are quantified. The main research tool is the questionnaire. At the same time, at this type of research, the criticism emerges that it does not give possibility to a deeper understanding of processes, problems or even of human behaviour. This incompleteness can be eliminated by qualitative methods, which give way to qualitative understanding of the phenomena, and to collect beliefs, attitudes and opinions. This type of surveys explores the scope of the research in details, mostly using small samples, in which representativity is not necessarily a target, it is characterized by resilience, reflexivity, interactivity and, furthermore, inductive approach. Methods in this group are observation, experiment, in-depth interview, expert interview, focus group, case study (Boncz 2015).

Both methodologies have advantages and disadvantages, which have to be interpreted purposely according to the survey type to be carried out. One criticism concerning quantitative surveys that the scales of the questionnaires are understood differently by the test subjects, while the object of the survey is the same according to the researchers. Furthermore, they do not show such background information as what influenced the reply of the subject (e.g. mood, living situation, environmental factors). However, as quantification is a prerequisite, and since objective, quantified and sufficient numbers of results are required, the use of quantitative methods is widespread.

One of the main criticisms of qualitative research methods is that the small number of cases means that generalisations are not possible and scientific results are limited. A further problem is that the criteria of objectivity, validity and reliability are not satisfied during the research.

The benefits of the two methods are indisputable, this way in certain disciplines, e.g. in health sciences, the combined use of the two methods is becoming more and more widespread, with the aim of eliminating their drawbacks and combining their benefits (Boncz 2015).

In my dissertation I used the most common primer research technologies to collect information, while this type of approach can be used parallelly for the aims of exploration, description and explanation. Its great advantage is that it is easy to accomplish, and the appropriately structured and completed questionnaires provide relevant information and are generally not burdensome for the respondent. The disadvantage however, is that subjectivity and sometimes insincerity emerge on both sides – on the side of the respondent and of the researcher, either. This type of questioning classifies as assisted questioning, since in the absence or eventual incorrectness of a response, the program warns and follows the logical links and jumps between questions. The disadvantage is that persons who have no internet/computer access may be excluded from the survey, this way significantly distorting the sample (Boncz 2015).

As a first step, I defined the categories of questions that I expected to answer my preliminary hypotheses, and organized them into logically and substantively coherent groups. I assigned some open questions with optional response choices. As for the method of interviewing, I finally chose online interviewing as it has the great advantage of being non-local, lower cost and less time consuming. I filtered out errors in content and form during a test questioning.

Data of the database I used in my seconder survey have been collected by transport operator BKV Zrt. since 1996. As the public service contract entered into force, this databese has also become

the initial database of the quality criterion – the safety indicator – since the number of accidents and their classification – as out of internal or external fault – are derived also from this system.

Using seconder data has several benefits: they are easily accessible, and, besides this, they provide such volume of data, which would be impossible or very difficult to obtain with primer methodology. Its drawback is that the data may become obsolete and may not provide a relevant answer for every question.

I used descriptive statistics to analyse my data, which is the most basic evaluation and assessment procedure. Its purpose is to receive information which summarizes the phenomenon described by the data and to draw up a primary situational picture (Jánosa 2023). As part of this, I created charts and figures to illustrate my research from the data obtained from the questionnaire survey and the secondary research.

In the questionnaire, I put up questions about safety from two approaches. These approaches, however, cover three directly related questions, which lead to my other area of more detailed study, to transport safety. The question concerning the vehicle category aimed to explore how safe the passenger felt, given the modernity of the vehicle. The feeling of safety included in the questions on the conditions of the trip is a subjective category, which largely covers the feeling of safety also generated by the fellow passengers. The third closed question, also included in this section, concerned the driver's driving style, which, although not objective, is more closely related to transport safety.

2.3.1. The context of empirical research

The results of an electronic survey conducted in 2021 were summarised in an article published in 2024 with fellow researchers (Khademi-Vidra et al. 2024). The online questionnaire is available at BKV Zrt.'s Facebook page. The responses received cannot be considered representative, as this form of the survey did not allow us to reach the part of the population who do not have internet access or are not Facebook users.

There were 4 weeks to complete the questionnaire between May and June 2021. In total, 274 responses were received. The central question of the survey was whether respondents also consider the same qualities important as those defined by the customer as quality requirements in the operator's public service contract. The vast majority of the questions (39 out of 42) were closed questions, with respondents having the opportunity to express their own opinions on three topics related to this research question. They could share their views on connections, the ideal stop and the vehicles. The analysis of the 274 responses received clearly identified areas for improvement (e.g. cleanliness of vehicles and stops, vehicle fleet). In the satisfaction survey, respondents were asked to answer specific statements by marking one response between "strongly agree" and "strongly disagree" on a five-point scale. There was a sixth response option relating to the conditions and other parameters of the journeys: "I can't judge" – this option was designed to give people who had not encountered this factor in their travels the opportunity to respond. However, for almost all 8 questions, the percentage of respondents who marked this answer was below 5%. We also asked people with cars about their use of the vehicle and the possibility of switching to public transport. The preliminary aim was to find out what they use their car for and when they would be willing to switch to public transport. For those respondents who for the question on frequency of use of public transport marked the response 'less often than once a month or never',,

the questionnaire was finished, so the actual number of respondents to the substantive questions was 258.

In addition to the descriptive presentation of the results, I also tried to show the relationships that emerged. Therefore, the hypotheses were tested using cross-tabulations with the statistical software package IBM SPSS Statistics 20.

2.3.2. The context of the quantitative survey

For the transport safety (accident) indicator assessed in the SLA system, incidents are classified into two broad categories – internal fault and external fault. As the number of external fault incidents is, by their nature, less under the control of the operator, they are given a weighting of only 0.2 in the rating.

The reduction of the number of external fault accidents in the accident black spots identified in my analysis can be achieved by raising awareness of public transport drivers to be more careful, and by traffic engineering suggestions and interventions. Of course, the proportion of internal fault accidents is the decisive factor in the assessment of this indicator, as they are clearly attributable to the fault of the operator. Within these, accidents with property damage and personal injury are given lower weightings, while fatal accidents are given the highest multipliers.

The traffic safety (accident) indicator is the weighted number of internal fault and external fault accidents per unit of performance of the vehicles providing the service, calculated and evaluated by sector (bus, tram, trolleybus). In addition to the line-related performance, the depot-bound runs and other auxiliary runs also have to be taken into consideration. A full sample, i.e. all runs of a time period of a given sector are examined.

The basic accident statistics used to calculate the indicator are derived from the data provided by the operator, while the performance data are derived from the ForTe system agreed by both parties.

Data on incidents causing traffic disruption have been collected by the operator BKV Zrt. systematically since 1996. The previous system basically involved an Excel-based spreadsheet in which the most important characteristics of accidents/incidents were recorded. The database on which my analysis is based is taken from the system currently in use, the so-called BBR (Accident and Insurance System). The great advantage of the system is that all documents related to the accident (accident investigation documents, police documents, correspondence with the insurer, other documents related to the accident) can be directly attached to the incident, and also simpler queries can be performed. These show, for example, the statistics on the depots releasing vehicles for a given period. Due to its intended use, the system has essentially a record-keeping structure and is not suitable for analysis on its own.

The database I examined, which contains data filtered for events reported to BKK (Centre for Budapest Transport) as the customer, covers 64,754 items for the period 1996–2023. In addition to the calendar date of the incident, the nature of the incident, its outcome, the cause of the accident, its sectoral classification, the type of vehicle and the route are also included.

To make the three sectors comparable, I have used a common projection base: available place kilometre performance, which is the basis for ordering and accounting for the service.

To identify the main trends, I used a six-point centred moving average, which gave me a trend that was easier to interpret and also smoothed out the fluctuations to some extent.

I carried out a concentration study for external fault accidents on the tram lines. To illustrate the presence and extent of relative concentration, I used a Lorenz curve.

3. RESULTS

3.1. Details of the results of the empirical study

The evaluation of the questionnaires confirmed the findings of the international literature, i.e. which parameters are the most important for passengers. These coincide with the quality requirements that the customer expects from the operator under the public service contract. Responses to the open questions revealed that more emphasis should be placed on the coordination of timetables at transfer points and on the comfort and cleanliness of stops. The eight dimensions of EN 13816:2002 define the parameters against which quality needs to be assessed. However, actual quality and passenger satisfaction may vary. The empirical research was limited to evaluations of transport quality parameters and did not include a detailed analysis of passenger behaviour, i.e. how specific quality characteristics influence passenger habits or behaviour.

I used closed questions to partially control the response process. Respondents could only express their own opinions in their answers to the open questions. However, they confirmed preliminary assumptions about which parameters are considered by passengers to be significantly more important and have a major impact on their perception of the trip. These include: the cleanliness and equipment (i.e. aesthetic appearance) of vehicles and stops; the frequency and punctuality of vehicles; information for passengers at stops and on vehicles; barrier-free accessibility of stops and vehicles; and other comfort parameters of vehicles (air conditioning, comfort, modernity). The perception of journey times and waiting times as determinants is mostly positive among respondents, so the aim is to keep them at a constant level or reduce them, respectively, by improving the service.

The question of the cost of journeys was deliberately left out of the survey, as it is not up to the operator to determine this. There were no questions about passengers, with the exception of noise, although these factors can have a big impact on the perception of a journey. However, a detailed assessment of this when travelling on certain routes could provide important feedback to help the operator achieve its goal of creating a sense of security. The question about crowdedness was indirect, as crowdedness is also a function of the route and travel time. Also, it is a problem that is difficult to solve other than by increasing the number of tram services, possibly by delaying the start of school or working hours.

The extreme parameters, i.e. those with which respondents were most satisfied (visibility of timetable information, information received in the vehicle) and where they were least satisfied (cleanliness of stops and vehicles, vehicle parameters) are all included in the requirements for the operator.

The hypothesis formulated in the research on the relationship between transfers and travel time clearly resulted in a more positive impact of transfer-free journeys on the perception of travel time. As described in the section summarising the findings of the international literature, the perception of travel time is influenced by many factors. The transfer is an "interrupting element" that can distort the perception of the journey in several ways, as it increases the perception of the travel time and, as the impression of the last leg of the journey has the strongest impact on the perception of the journey, it has a decisive influence on it. There is no question, therefore, that there is a strong case for cross-city services to cover travel needs.

However, it is important to highlight that vehicles are also among the emerging areas for development. A new vehicle can both increase aesthetic and cleanliness-related satisfaction, while

at the same time enhances transport safety-related security, thus it is crucial. As this is a key issue not only for the passengers using the service, but also for the operator, it is essential to examine the issue of security in this context. A more modern fleet can significantly improve passenger comfort and satisfaction, while reducing the operator's maintenance costs and making its operating budget more predictable.

The online survey also included the identification of characteristics of respondents, based on which:

- just over two thirds of respondents were male, with nearly 80% in the working age group (20–60 years), almost 60% in full-time employment and almost a quarter of them students,
- 44% of respondents have a car, more than 87% use public transport daily or several times a week, a significant proportion of them in the morning (66%) or afternoon (61%), and a significant proportion (almost 41%) use public transport after 5 pm in the evening,
- public transport is most used by people aged 20–29, full-time employees and students,
- a quarter of car owners also use public transport on a daily basis.

In terms of the destination of the journeys:

- the proportion of people using public transport for getting to the place of work or a leisure activity is almost the same at almost 70–70%,
- slightly more than half of respondents (56%) also use this mode of transport for shopping and for running errands.

By proportion of people choosing different modes of transport:

- 80% travel by bus,
- 72% by tram,
- 62% by metro.

16.3% of respondents travel by train.

For the last three questions, which asked if they would use public transport if they could reach their destination without having to change, if the journey time was shorter or more convenient, or if the vehicle was less crowded, almost 90% said yes.

For the questions on the evaluation of stops, respondents had to react to the statements made. The responses for an ideal stop are consistent with the responses to the statements we have made:

- cleanliness and equipment were rated lowest: 58% for the former and 48% for the latter, with a neutral or worse rating,
- the overall visibility of timetable information was rated good, with an average score of 4,
- just over 63% consider it appropriate if the accessibility of a stop is average.

Respondents to the open questions on an ideal stop would like a stop sheltered from rain and wind, and many also criticised the lack of cleanliness, due to the lack of cleaning and rubbish bins. In addition, they would like easy, barrier-free accessibility and the installation of an electronic information board. Respondents consider comfort to be important, which they believe could be reflected in more benches, shaded stops in summer and adequate lighting.

According to the cross-stability analyses:

- 81% of respondents consider the distance between their home and a public transport stop to be very good or good,

- it has also been shown that departure and delay information is more important for passengers living further away from the stop (p=0,007).

For questions on vehicles, the temperature of the vehicles was the main negative factor (63.8%), followed by roughly equal proportions (45-45%) for cleanliness and the comfort of the seats (which was asked in conjunction with the availability of sufficient seats, so crowding was probably the main factor). The descriptive statistics confirmed that passengers choosing a full-price monthly pass are more dissatisfied with the cleanliness and aesthetics of the vehicles (68.6%) than passengers using a reduced-price pass (53.5%) in our research sample.

In addition to the above, the following relevant findings could be made:

- a relatively high proportion of people (42%) also complained about boarding a vehicle,
- this coincides with the demand for barrier-free accessible vehicles in the open responses,
- satisfaction with in-vehicle passenger information is outstanding, at 79%,
- only preceded by sufficient handholds, which are above 80%,
- the proportion of people satisfied with the number of seating and standing places (67.7%) was relatively good,
- above 60% of those who consider the vehicle to be modern and safe (64%) and those who consider that there is enough space for wheelchair and pushchair users (62.6%).

As for the ideal vehicle, the most frequently mentioned was a low floor, air-conditioned, modern vehicle. The need for cleanliness and displays has also been expressed here, just like at the bus stops. Other comfort concerns include more comfortable seats, and several people want environmentally friendly vehicles equipped with cameras.

Women are also more critical about the cleanliness of vehicles. The perception of seats, standing places and handholds is similar for both sexes. However, female respondents consider that the number of spaces for pushchairs and wheelchairs is insufficient. Women and men have almost the same perception of on-board information and luggage space, but the former feel less safe when travelling. They are equally dissatisfied with the temperature of the vehicles.

When examining travel conditions and other parameters:

- most passengers were satisfied with the driving style of drivers (69%),
- and their courtesy (67%),
- and were more likely to agree on the presence of comfort and availability of sufficient space (61% and 63% respectively),
- while the most disturbing sound effects were those of the vehicle and fellow passengers.

Among the other parameters, important parameters stipulated in the public service contract with the operator, such as the frequency of vehicles (linked to the cancellation indicator) and the regularity of the service (both treated as one), as well as departure and delay information, had to be assessed. The planned evolution of a journey suggests a kind of complex satisfaction, which can be influenced by many factors and does not fully reflect overall satisfaction with the service:

- 65% are mostly satisfied with the frequency of service,
- 70% of respondents are also satisfied with the information provided on departure and delay.

Almost three quarters of respondents consider their travel time to be adequate or short, while more than a fifth feel it is too long. We could not find a correlation between travel time perception and demographic characteristics. 75.5% of respondents to the questionnaire have to change during their journey. In response to the open question "In your opinion, how could the transfer option you use be made more convenient/practical?" 97 responses were received. Most of the responses suggest the harmonisation of timetables, merged, longer lines (mentioning interconnected tram networks

as a positive), closer stops and more convenient, cleaner stops. Waiting times for transfers are considered short or adequate by 68%, and less than a quarter of respondents perceive them as too long. At the most common destinations, twice as many men as women have to change. This can be explained by the fact that men are more likely than women to choose to work farther away from home.

The results of the survey proved that travelling without transfers is more positively valued in terms of travel time ($p<0.001$).

16.3 per cent of the respondents contacted customer services. However, a higher proportion ($p<0.01$) of respondents who considered the travel time too long contacted customer services. In their case, the proportion of satisfied and dissatisfied respondents was about equal. Almost 70% considered that the customer service agent was helpful and polite. Overall satisfaction, however, was 41% satisfied and 59% neutral or dissatisfied with their experience of customer service. The method of contact was 50% electronic, 42% by telephone and only less than 30% visited the helpdesk in person.

3.2. My investigation related to the transport safety (accident) indicator

My detailed investigation covered one of the quality indicators included in the Public Service Contract between BKV Zrt. and BKK Zrt., the transport safety (accident) indicator, and the database on which it is based. With the inclusion of this indicator in the quality requirements of the contract valid as of 2012, it has become not only a key factor for compliance with passenger requirements, but also a "basic element" of financing. The issue is also closely linked to the European Union's sustainability objective of significantly reducing road fatalities, which I described earlier, as a necessary step to improve transport safety.

In the context of defining the relevant environmental parameters, I will show the trend in the number of traffic accidents with personal injury in the country and in the capital city:

- data are available from 2005 onwards for both territorial units, until 2012 at country-wide level, while in the capital there was a steady decline until 2010,
- the former shows a slight increase from 2012 onwards, with only small year-to-year variations until 2020,
- in the capital, there has been almost continuous growth in the decade since 2010, with the exception of 1 or 2 years, but less than 10% per year.

In line with the Zero Vision objective, the most important is the continuous reduction of fatalities: a decrease can be seen continuously until 2013, followed by a slight increase and a slight decrease until 2020. In the capital, 2011 is the lucky low point year, followed by a 5-year upturn, followed by stagnation in the period 2016–2019, broken by a drop during the pandemic. However, similar to the national figures, the upward trend then started again.

My study initially covered the entire accident database of BKV Zrt., i.e. the period 1996–2023, and included all three sectors for this indicator. However, I then analysed one sector, tram transport, in detail over a limited time period. The reason for this is that the tram sector is the one in which the data can be compared on a correlated basis, and in the time period already evaluated for the analysis, there has not been a systemic renaming of routes or route modifications as in the case of the bus sector. On the other hand, the personal injuries and material damage caused by accidents in the rail-bound sector are of such significance that we must pay serious attention to reducing them at all levels and in a timely manner.

Based on the long-interval (1996–2023) evolution of the number of accidents in the three sectors studied:

- the place-km performance figures for the tram and the bus sectors are roughly the same for the last 7 years, but the accident figures are much higher for buses,
- in all sectors in general, possible overtime due to driver shortages, particularly in the bus sector, significantly increases the internal fault accident rate,
- the number of accidents has been decreasing over the longer term, as in the national data, but with greater fluctuations from year to year, which I have used a moving average to smooth out.

The key question for the transport safety (accident) indicator is whether the accident is internal fault or external fault. Although the weight of external fault accidents has a much smaller impact on the quality of service indicator, the proportion of accidents in the total number of accidents shows how much attention should be paid to this category. It can be seen that:

- in the tram sector, the vast majority of accidents are external fault (80–90%),
- narrowing the observation to the last 10 years for buses and trolleybuses in a range of 10–15%, this category generally fluctuates between 50 and 70%.

Moving beyond the categories used in the calculation of the accident indicator, I examined the proportion of internal fault accidents with property damage and internal fault accidents with personal injury as a proportion of all accidents. Since the analysis of these two together gives the total number of internal fault accidents, the curve of internal fault incidents involving property damage is very similar to the base set of which it is a part. The bus and trolleybus sectors have a higher proportion of accidents with material damage. One reason for this is the sharing of roadways with other vehicles (even in dedicated bus lanes), which means that the range of traffic situations that can lead to accidents is wider.

3.2.1. Detailed analysis of the tram sector

For the 7 years I studied (2017–2023), there is a periodicity that can be observed: usually the months of September, October and December have the highest number of accidents. Ranking each route by the number of accidents over the wider (1996–2023) and narrower time intervals shows that 11 of the 15 most problematic routes are the same:

- accidents on these 15 routes account for 77% of all accidents,
- analysing the fault rate of accidents, I found that the percentage of external fault accidents ranges from 74 to 98%,
- for the 10 routes with the most accidents, this ranges from 86% to 98%.

As this ratio is extremely high, I have subsequently examined the reasons for this in detail.

The number of accidents on these routes can be greatly influenced by their length and frequency in terms of the timetable, so to facilitate comparison I have used the specific indicator per place-km already used.

The Tramlines with the three highest values – 24, 51 and 42 – differ by orders of magnitude in their specific averages compared to the other routes. Therefore, I considered it important to examine in detail whether it might be worthwhile to introduce a multiplier for these lines in the calculation of the accident rate to make their share "fairer". Taking the average of this specific accident rate for all the 26 routes I have studied, it is 0.12 accidents per 1 million place-km, i.e. each of the three top routes is twice the average.

First, I examined the proportion of accidents and the types of accidents that occur most frequently on these routes. Overall, their performance share is relatively low or average:

- for tram 42, the rate of external fault accidents (94%),
- while on route 51, the percentage of internal fault accidents (26%) is high.
- Tram 24 and 51 also have high rates of accidents, the latter being particularly notable for the proportion of material damage caused by internal fault accidents of this type of accidents on all routes.

In what follows, I have examined the reasons and details behind these values.

Overall, I have found that:

- for two of the routes with high accident rates, the causes are mainly attributable to internal fault accidents,
- a downward trend is observed on route 24,
- in view of the stagnation of accidents on tram line 51, consideration should be given to drawing the attention of the operator to the possibility of additional training for drivers on the line,
- the spike in the high number of external fault accidents on tram line 42 in 2019 was due to drivers with little experience, and the introduction of the CAF vehicle type on the line in 2022 could have caused a similar increase in the number of incidents.

So, for these three routes, I have not been able to find any reason to justify the introduction of a correction factor.

I then carried out a concentration test. Relative concentration is a kind of manifestation of the variation (dispersion) of the values of the units of a population, the extent of which is shown by the Lorenz curve. Since the concentration test showed that, for example, in 2023, 40% of the lines would be affected by 70% of the external fault accidents, I have then examined which lines are the most problematic in this respect.

As I have already found, the vast majority of accidents in the tram sector as a whole are external fault. Although the multiplication factor for the calculation of the accident rate is only 0.2, its numerical significance is such that I consider it inevitable to examine it in detail. For the top ten routes, at least 9 out of 10 accidents were external fault. I thought it was important to show the additional relations because their quantity is significant in the overall set.

Categorised by type of accident:

- third-party vehicle collisions – 78%,
- passenger accidents – 12%,
- pedestrian accidents – 9%,
- the other cases (collision with an object, collision with own vehicle, derailment, other accident, animal hit) together are under 1%.

I looked at the nature of the incidents within the internal fault accidents: most problems are with collisions with third-party vehicles, 63% for all routes. The second, but much less frequent, type of accident is derailment, followed by collisions with objects, passenger accidents and own-vehicle collisions, with about the same proportion – half proportions of that of the second place – compared to the total.

I have looked in more detail at the highest proportion of routes with internal fault accidents and selected those that show an increase or stagnation for several years after the 2020 downturn. Except

for tram line 2, which despite a steady increase had no such accidents in 2023, these are also the top routes with internal fault accidents in 2023.

Looking at the internal fault accident rates for each vehicle type over the last 7 years, it can be seen that the TW6000 type has had the highest internal fault accident rate in each year. After 2019, the share of TK2 and in 2023 the share of ICS increased, the latter relatively significantly, by 13% compared to the previous year.

I have been able to identify accident black spots by mapping, where my investigation included the exploration of the possible causes of accidents. I thought it appropriate to use a map for illustration because the location marking of each incident is not consistent in the available database. Although it required considerable manual data entry to assign GPS coordinates to each accident site, the above uncertainties were largely filtered out, resulting in a database that was easy to analyse.

I have managed to identify three points that are high on the list of accidents.

- One of these is located in the 14th district, at Szabács utca. There are no traffic lights at the right-turn when crossing the tramway running on the side. Car drivers must also look out for the tram coming from behind – which they cannot see if the tram in the other direction is at the stop. While turning left, drivers must be able to see both the tram coming from behind and the tram coming from the other direction in time to avoid an accident. 100% of the accidents here are external fault and in all cases they occurred because the tram was not given the right of way.
- The next of these problematic intersections is at the intersection of Szabadkai út – Gubacsi út in the 9th district. At this intersection without traffic lights on tram line 51, almost all accidents were external fault by a failure to give way. At the intersection, the road crossing the middle-run tramway from several sides and directions means that drivers would have to pay increased attention to trams potentially coming from two directions and to transversal traffic in both directions at the same time. The traffic lanes are not physically separated from the tramway, and their width and condition do not allow for the separation of road traffic running parallel to the tramway.
- Finally, the third intersection with the highest accident incidence in the 8th district is the intersection of Orczy út and Kőris utca. The intersection, which initially had no traffic lights, was fitted with traffic lights in the second half of 2023, and there were no accidents in the last two months of this year. The earlier problem was similar to that in the 9th district, where a section of transversal traffic crossing the middle-run tramway from several directions required divided attention from drivers.

A common feature of the accident black spots I identified is that they did not have an active device to control the flow of traffic during the period under study (or in the case of one location, for the majority of the period). The importance of this is shown by the fact that there were no more accidents at the Orczy út – Kőris utca intersection in 2023 after the intersection was rebuilt with traffic lights.

In examining the evolution of accidents, I could not leave out the factor that can have a decisive influence on the evolution of the number of accidents: the time spent in practice by the tram driver. Here, I could basically compare against two dates, depending on when the driver obtained the licence for the vehicle category or vehicle type. I have grouped the accident participants into different categories based on their length of experience relative to these two points in time. Already for the total number of accidents, it is clear that the proportion is higher for those with the least experience, but the difference is particularly striking when looking at the internal fault (column 3) and external fault (column 5) accident rates for the type of vehicle. I have grouped those with more

than 10 years' experience into one category, so the results can be a little misleading, but their proportion of experience by vehicle type clearly shows how much their experience can help to avoid or reduce the risk of an accident.

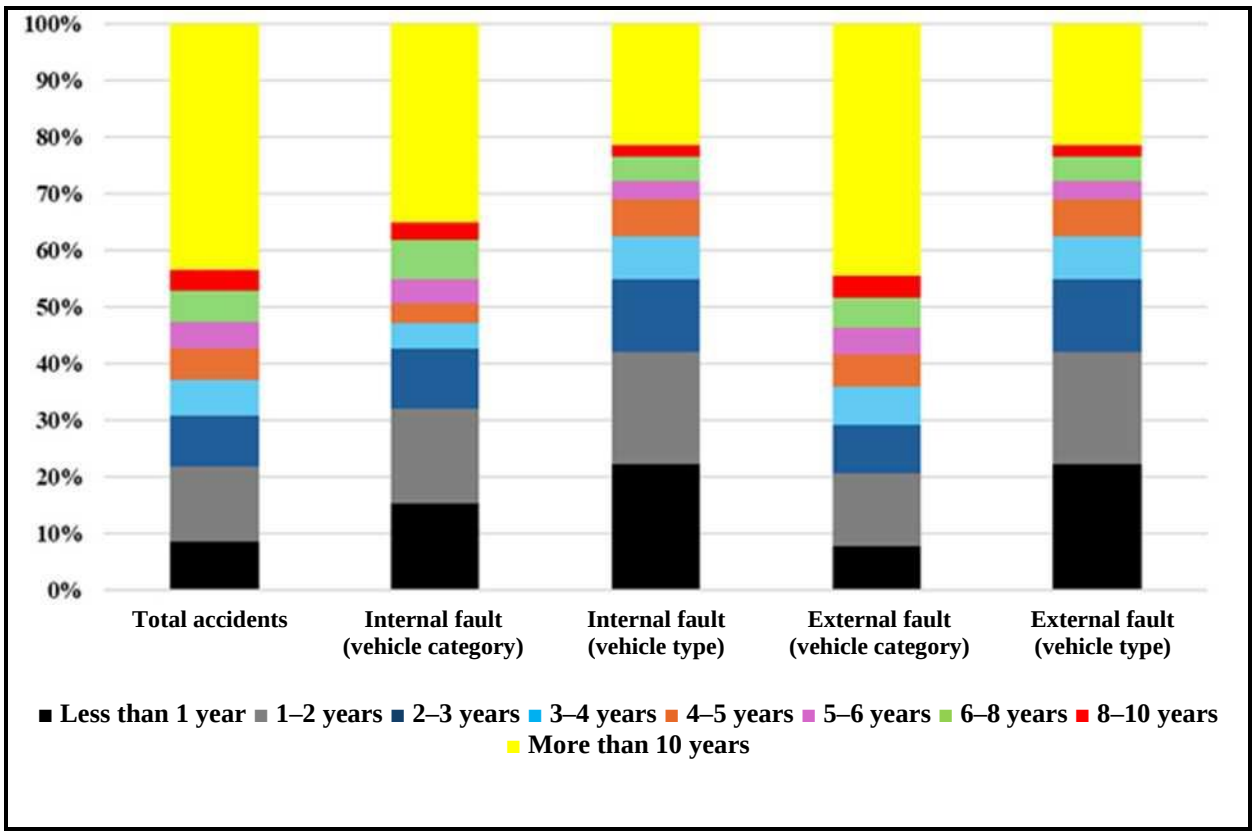

FIGURE 2: ACCIDENT INVOLVEMENT RATE ACCORDING TO DRIVER EXPERIENCE

Source: edited by the author (2024), BKV Zrt. BBR system

The number of internal fault and external fault accidents per place-km makes the routes comparable. In my further analysis, I used the routes with a high specific value for external fault accidents to compare the five highest ranking routes with the five lowest ranking ones. The aim of my study is to investigate how accidents on the line may have been influenced by the drivers' practical experiences. I excluded lines with an average performance below 40 million place-km per year from the study to avoid bias due to their relatively low performance and therefore higher specificity.

The accident trends for the lines I selected over a 7-year period show relatively low rates of external fault accidents, so I included three other lines with higher accident rates – lines 17, 19 and 28 – in my analysis. What is striking is that for 3 out of the 5 lines originally selected, drivers with more than 10 years of experience represent a much larger number. One reason for this may be that I did not divide the drivers' experience, or more precisely the years of experience related to the type of vehicle, into categories of equal length. On tram line 51, 67% of accidents are caused by the tram not being given the right of way, and the vast majority of these accidents occur at a problematic intersection. I have previously identified this intersection as one of the accident black spots. In other words, although it can be seen on this route that those with little experience are involved in proportionally more incidents, the high proportion of the most experienced is attributable to the problem route.

For vehicle types, the accident database needed to be filtered and clarified. To resolve anomalies caused by different terminology, I have introduced uniform designations for vehicle types.

To compare vehicle types, I calculated the number of accidents per million km driven.

My study was designed to find the relationship between the type of vehicle on a given route and the rate of accidents they are involved in. This can be considered for routes where there are several types of vehicles and where they provide a comparable level of traffic performance (e.g. CAF9 and TK3 for route 1, CAF5 and TK2 for route 17). A method based on the expectation of an approximate order of magnitude of the place-km ensures that I can compare data from routes operating at the same time of day with a relatively even distribution, while excluding the possibility that where a vehicle type not typical of the line appears only when running out on the track or returning to the depot, with low traffic volumes, it may interfere with the analysis by providing extreme numbers of accidents for the particular vehicle type on the line analysed.

In the following, I have examined other aspects of the two vehicle types with the highest number of accidents per million km travelled. The TW6000 was first released for traffic in 2001, initially for the tram line 50 and later for the newly developed tram line 3. This type is used on routes 3, 24, 37, 42, 50, 51, 52, 62, and 69.

In the analysis of the accident rate of the vehicle types, I have already demonstrated that this type has the highest accident rate per million kilometres travelled and the highest accident share (30%), although its share in terms of place-km is "only" 16%, which is the highest after the Combino. Consequently, I have examined the routes on which this type of tram runs:

- the highest value for 7 out of 10 routes is for the TW6000,
- however, it should be noted that the CAF5 tram type with the higher values on the three routes appeared for the first time in the 7-year period under consideration, which in itself may represent a higher multiplier factor in the number of accidents.

For the CAF5 vehicle type, I have calculated the accident specific values for the relevant routes for the time period 2017–2023. I have not included in the analysis those routes where the place-km was below 25,000 or where the vehicle type had a low share of route performance. Apart from the extreme values, which are only rarely present on the given route, on 6 out of 9 routes the CAF5 has the highest accident value. For these routes, I have looked at the evolution of the indicator on an annual basis. This shows that the introduction of the CAF5 on the new line has led to an extreme increase in the number of accidents (50–70 accidents per 1 million km). For the 3 routes where CAF5 is not the highest, I also carried out a year-by-year study to see what general conclusions can be drawn, either for the CAF5 vehicle type or possibly for the introduction of a new vehicle type on the line.

From 2017 onwards, the CAF5 was the most frequently used vehicle in terms of kilometres travelled on tram line 17. In the first two years, T2 still had a comparable performance – and then it was rolled out – yet the relative number of accidents in both years was higher for CAF5. The TK2's comparable performance started in 2018, but even in 2019 it still had only about half the mileage of the CAF5. Thereafter, in 2021–2022, the TK2's kilometres travelled were less than a tenth of those of CAF5, and in 2023 (with a fifth of the kilometres travelled) the proportional indicator slightly exceeded the same value for CAF5.

On tramline 56, the CAF was put into service from 2023, and at that time its performance was only 40% of that of the TK2. However, its accident rate slightly exceeded that of the same type of vehicle.

Finally, I also examined the evolution of the indicator for the same years on line 69: the new type appeared on this line from 2021, but in the first two years the performance was a fraction of that of the main vehicle type and there were no accidents. In 2023, when its performance had already risen to almost 20% of that of the TW6000, the value of the indicator also rose sharply.

For one of the three routes, a higher value of the CAF5's proportional accident indicator can be seen throughout, except for the year 2023. However, in the other two cases, it is not yet possible to draw a general conclusion from individual relevant years.

The analysis of line 50 revealed the introduction of a new type: the line, served only by theTW6000 fleet, gradually started to include CAF5 trams from 2022. On route 3, however, the situation was somewhat reversed: while the infrastructure of the Hűvösvölgyi and Üllői út lines was being upgraded to accommodate the new CAFs, the trams already delivered were operating on existing and suitable lines. After the completion of the most necessary reconstruction of lines 50 and 56, the CAF rate on line 3 decreased, while the TW6000 rate increased.

In support of my hypothesis, I also examined in detail the routes where the overall accident rate for CAF5 vehicles was higher. Here, I mainly focused on the rates of passenger accidents and collisions with third-party vehicles: the CAF5 appeared on route 50 from 2022, when its mileage was only eighth of that of the other vehicle type. In 2023, however, it was already slightly above the TW6000, while the number of foreign vehicle collision accidents was significantly higher.

Route 56 provides similar data: the CAF5 appeared on its route in 2023, with a traffic performance that can be used as a basis for comparison. However, for that year, the number of collisions involving a third-party vehicle already exceeded that of the TK2 type, which also served the line, with around three times the mileage. There were no passenger accidents with the CAF5 on line 56 in 2023.

3.3. Testing hypotheses

Research question 1: Which passenger satisfaction components contribute to increasing the share of public transport users compared to private motorised transport?

My preliminary hypothesis: *Journey time optimisation is a high priority attribute of passenger satisfaction.*

The validity of the hypothesis: During the questionnaire survey conducted with my fellow researchers, I asked several questions about transfers. Of the three related questions, one provided the possibility to give a free-text answer. The first question was how to make transfers more convenient and practical. Most respondents mentioned short transfer times and the coordination of timetables. By addressing people with cars, I wanted to prove the premise that people with cars often do not choose public transport because of the multiple transfers. The positive response of almost 90% of the respondents that they would choose public transport if they did not have to transfer confirms the importance of cross-city services, such as the interconnected Buda tram network, which was set up in the last decade for this purpose. Waiting times during transit were considered short or adequate by almost 70% of respondents. The calculation performed confirmed the hypothesis ($p<0,001$).

The evaluation of the responses to the questionnaire survey clearly showed that respondents have a more positive perception of travel time if they do not have to transfer, so I consider my first hypothesis to be confirmed.

Research question 2: Considering the Budapest tram network what local area characteristic can be identified which affects service quality negatively?

My preliminary hypothesis: *The endowments of urban structure and traffic management on transport routes have an impact on the development of a specific indicator of service quality.*

The validity of the hypothesis: I have carried out a detailed analysis of accident data for my selected public transport sector, pre-cleansing and categorising them. I assigned GPS coordinates to the accidents and plotted them on a map. The detailed analysis has allowed me to identify three black pots with a much higher number of accidents compared to the other accident locations. In these locations, there are no traffic lights to assist road users. In my view, more serious traffic engineering interventions are needed at these locations to reduce the number of accidents. In one of the black spots I identified, a traffic light was installed in the second half of 2023. Prior to this, there were on average 4–5 accidents per year at this junction, but there have been no accidents at this location since then.

At the accident black spots I have identified, there are no traffic lights to assist pedestrians. The intersections that were upgraded at the end of the time period studied did not have any accidents in the same year afterwards, so I consider my second hypothesis to be confirmed.

Research question 3: How does the emergence of a new public transport technology in a local area affect the qualitative attribute of service quality, i.e. safety component?

My preliminary hypothesis: *The introduction of a new type of public transport vehicle in a given local area reduces the number of accidents on that network.*

The validity of the hypothesis: In the period under study, two sub-types of a new type, the CAF5 and CAF9, were newly put into service. When analysing these routes in detail, it became clear that

the number of accidents increased significantly in the period after entry into service compared to other types of vehicles on the same route. Since these vehicles arrived in several stages on different lines in the capital, I have been able to draw conclusions for three lines, lines 3, 17 and 19 so far. Following a jump in the specific accident rate per kilometre performance, a decrease in this indicator is seen on average after a minimum of 12 months. For the other two lines with CAF5, lines 50 and 56, the assessment period is short, given that they were only put into service in 2022 and 2023. My assumptions suggest that line 50 could already show some decline in 2024. The arrival of a new type of vehicle on a given route presents a new challenge not only for the driver, but also for other road users driving parallel and perpendicular to the line.

My study, carried out with time series analysis, showed an increase in the specific number of accidents. Although the parameters of the studied routes are not fully comparable – not even because of the number of new types of vehicles that appear on them in a scheduled manner – it can be generally stated that it takes at least 12 months for this indicator to decrease, so I consider my third hypothesis to be refuted.

Research question 4: What is the impact of the professional qualifications of those directly involved in the service on the measurable quality of the public transport service in the local area?

My preliminary hypothesis: *The human resource management of a public transport operator in the local area has an impact on the number of accidents caused by internal or external fault.*

The validity of the hypothesis: An attribute of the accident database is the date of the driver's licence for the category or type of vehicle. I categorised the years of experience relative to the time of the accident. Analysing the resulting database, I found that the number of accidents in both the own fault and external fault groups is strongly influenced by the experience of the drivers, i.e. those with more experience are proportionally involved in fewer accidents.

My detailed analysis of the routes clearly showed that drivers with little experience are more involved in traffic accidents. Thus, the quality of service of a public transport operator, which is characterised by an accident indicator, is strongly influenced by the professional experience of the operators and the assignment of drivers to certain lines with different transport safety characteristics, so I consider my fourth hypothesis to be confirmed.

4. CONCLUSIONS AND PROPOSALS

The evaluation of the questionnaires confirmed the findings of the international literature, i.e. which parameters are the most important for passengers. These coincide with the quality requirements that the customer expects from the operator under the public service contract. The actual quality and the passengers' satisfaction can defer.

The hypothesis formulated in the research on the relationship between transfers and travel time clearly resulted in a more positive impact of transfer-free journeys on the perception of travel time. As described in the section summarising the findings of the international literature, the perception of travel time is influenced by many factors. The transfer is an "interrupting element" that can distort the perception of the journey in several ways, as it increases the perception of the travel time and, as the impression of the last leg of the journey has the strongest impact on the perception of the journey, it has a decisive influence on it. There is no question, therefore, that there is a strong case for cross-city services to cover travel needs.
It is therefore clear that more positive passenger perception needed to increase the share of public transport in order to achieve the EU's sustainability objectives is served by network organisation methods that cover travel needs, crossing the city or the given territorial unit and minimise the number of transfers. My findings in this respect are summarised in the following conclusion:

1. My analysis of the travel preferences of the urban public transport target group, using scientific methods, has identified the need to apply sustainable transport management practices, in particular to optimise the number of transfers, which is a key determinant of travel time perception.

However, it is also important to highlight that the areas for improvement identified in the responses to the questionnaire included the quality of vehicles. The ability of a vehicle to increase both aesthetic and cleanliness-related satisfaction, as well as a sense of safety related to road safety, is crucial. Since this is a key issue not only for the passengers using the service, but also for the operator, it is essential to examine the issue of security in this context. With a more modern fleet, passenger comfort and satisfaction can be significantly improved, as well as reducing the operator's maintenance costs and making its operating budget more predictable.

Although a measurable component of service quality defined in the public service contract, the accident indicator, does not directly affect the punctuality indicator (timetable punctuality), because it is calculated without taking into account delays due to accidents, it does increase the travel time of passengers using the service, sometimes forcing them to change vehicles. Thus, an accident can be a decisive factor in determining whether a journey goes according to plan and satisfaction.

The database of the surface public transport network in Budapest covering a period of almost 20 years, which I have analysed, shows the differences in the characteristics of the different sectors. The place-km performance data for tram and bus sectors are roughly the same for the last 7 years considered relevant, but the accident figures are much higher for buses. The reason for this is that buses, which use the same surface as other road transport vehicles, are much more exposed to accidents than rail-bound vehicles. In the tram sector, the vast majority of accidents are due to external causes, with the proportion ranging from 80-90% over the whole period under study. In the case of the bus and trolleybus sectors, again for the last 7 years relevant to comparability, the proportion of accidents due to external causes fluctuates within a range of 10-15%, generally

between 50 and 70%, so that over a long time series there is a verifiable difference in magnitude between the same indicators for the different sectors. In order to make the assessment of service quality more objective, I have drawn the following conclusion:

2. In a review of the integrated public transport system in a given local area, I have used data to demonstrate that the transport safety parameters of the different subsystems differ significantly. For the purpose of objective evaluation, I proposed a methodological change in the calculation of the transport safety indicator for the tram sector, which allows the quality of service to be characterised, and I have modelled its impact.

In my opinion, the indicator can be calculated with the following formula:

$$K_{accident\ BKV} = \frac{0{,}1I_{BKV} + 3S_{aBKV} + 5S_{szBKV} + 10S_{hBKV}}{P_{BKV}}$$

where:

- I_{BKV}: internal fault accident (no.),
- S_{aBKV}: internal fault accident with property damage (no.),
- S_{szBKV}: internal fault accident with personal injury (no.),
- S_{hBKV}: internal fault fatal accident (no.),
- P_{BKV}: the Operator's mileage (million train-km).

The accident rates calculated with the new methodology are in bonus categories for all elements of the period under review, and except for two periods the % values are higher. The advantage of applying the new methodology is that it provides more objective measurement results than the one previously used; the responsibility of the operator concerned can be examined in cases over which it has direct control. If the bonus values calculated using the new methodology modelled were to be compensated by the customer, dedicated funding could be made available for measures to achieve the EU's sustainability and transport safety objectives by reallocating existing resources.

My research shows that in order to achieve the objectives of the Zero Vision 2050 for improving transport safety in the European Union, it is important to increase the share of public transport in the total displacement and mobility in a given territorial unit. Understanding user preferences also highlights the importance of the role of transport safety. At the same time, the safety of public transport itself needs to be improved in order to achieve this objective. Only four of the Hungarian public transport contracts I examined contain some kind of quality incentive to improve transport safety, so I have come to the following conclusion:

3. In the course of my research, I concluded that transport safety, which has a direct impact on the attractiveness of public transport, is of crucial importance for achieving the sustainability objectives of the European Union, and therefore I proposed to emphasise the role of transport safety as one of the quality assessment criteria for the public service contract of a public transport operator operating in a local area.

I propose that an accident indicator with the volume of +/- 1% of the annual fee, as a quality assessment component of public service contracts of public transport, could be an appropriate safety incentive to improve the traffic safety component of service quality.

In my research, I was able to analyse a relatively well-structured data set in terms of transport safety. However, the structure of the database is primarily designed to improve the management of insurance claims and, although it is the basis for periodic quality assessment, it is not suitable for territorial analyses.

A difficulty in analysing the data was that the naming and, in some cases, the numbering of many streets and squares changed over the relatively long study period, and the naming of some new vehicle types and those being withdrawn was inconsistent. For the above reasons, I propose that in the case of the BBR system that records accident data at BKV Zrt., the person who investigates accidents should indicate the accident scene with GPS coordinates, and the type of vehicle involved in the accident only with the track number. These clearly define the parameters of the incident in a way that can be analysed and retrieved later.

4. Based on my investigations, I have verified that the accident data examined by time series analysis show a periodicity. Therefore, I have concluded that it is necessary to carry out an annual examination of the accident black spots identified for the period under consideration and to propose traffic engineering modifications to them.

Results of my analysis are in Section 3.2. When identifying accident black spots, I established the lack of active traffic control as a common characteristic. As accidents occur so frequently at these intersections that the operator suffers significant financial losses – not only due to the material damage to vehicles and the categorisation related to the inclusion in the indicator required by the public service contract, but also due to the difficulty of replacing the vehicles that are out of order – it is of utmost importance to notify the customer and the competent road administrator (in this case Budapest Közút Zrt.) of the need to change the traffic control as soon as possible.

In examining the evolution of accidents, I could not leave out the factor that can have a decisive influence on the evolution of the number of accidents: the time spent in practice by the tram driver. Here, I could basically compare against two dates, depending on when the driver obtained the licence for the vehicle category or vehicle type.. Already for the total number of accidents, it is clear that the proportion is higher for those with the least experience, but the difference is particularly striking when looking at the internal fault and external fault) accident rates for the type of vehicle. Based on the above:

5. I have found a clear correlation between the data on accidents affecting the quality of service and the management of human resources in a public transport subsystem in a given spatial structure.

To reduce this effect, I propose that drivers with less practical experience for a given type should gain their first 12 months of practical experience on routes already served by that vehicle type, and that new drivers who have just obtained their licence and are starting their careers should start on routes with the lowest overall accident parameters.

5. SUMMARY OF NEW SCIENTIFIC FINDINGS

1. In the course of my investigations, I have come to the conclusion that, in order to improve service development for sustainability purposes, the role of the traffic safety indicator, which is a key component of the territorial assessment, should be emphasised among the quality assessment criteria for the public service contract of a public transport operator operating in a local area.

Only four of the public service contracts in the Hungarian cities surveyed include an analysis of annual traffic safety data as part of the quality of service evaluation. Of these, in the Budapest example examined in more detail, the indicator represents an incentive for the operator of +/- 0.6% of the annual public service charge.

2. Based on my analysis, I have found that the methodology for calculating the transport safety indicator used to assess the service cannot be the same when assessing the transport safety risk of each sector of an integrated transport system operating in a given local area.

My investigations have clearly shown that the number of accidents involving buses and trolleybuses on tracks that are typically not separated from road traffic is about four times higher than for trams on rather separated tracks over the time series studied. When looking at the rate of internal fault accidents that occur, the proportion of accidents is roughly constant at 10–15% for trams over the time horizon studied, while for buses and trolleybuses it is around 40%.
I consider it appropriate to change the methodology for calculating the transport safety (accident) indicator used in the tram sector: while keeping the rate for internal fault accidents that actually affect the quality of the public operator's service, I consider it appropriate to use a weighting of 0.1 instead of the 0.2 used for external fault accidents. Thus, in my opinion, the following formula would be more appropriate for the fixed rail sector to define the transport safety indicator:

$$K_{accident\ BKV} = \frac{0{,}1I_{BKV} + 3S_{aBKV} + 5S_{szBKV} + 10S_{hBKV}}{P_{BKV}}$$

where:

- I_{BKV}: internal fault accident (no.),
- S_{aBKV}: internal fault accident with property damage (no.),
- S_{szBKV}: internal fault accident with personal injury (no.),
- S_{hBKV}: internal fault fatal accident (no.),
- P_{BKV}: the Operator's mileage (million train-km).

This would ensure that the responsibility of the operator concerned can be qualified in cases over which it has direct control. However, the annual analysis of the rates for external fault accidents, determined by urban structure and spatial structure endowments and the behaviour of others, would still provide the opportunity to identify the causes of accidents and black spots on a spatial basis. Although the value for the number of external fault accidents could be lower than 0.1 when compared with other sectors, given that transport safety recommendations suggest that defensive driving could help to avoid some of the external fault accidents, I propose to keep the value at a minimum.

3. Based on my investigations, I have verified that the accident data examined by time series analysis show a periodicity. Therefore, I have concluded that it is necessary to carry out an annual examination of the accident black spots identified for the period under consideration and to propose traffic engineering modifications to them.

Through the processing and development of the accident database, I was able to identify accident hotspots by means of map plotting, where my analysis also included an examination of the possible causes of the accident. The advantage of the map representation is that it provides an exact location and an analysable structure, which allows the identification of transport safety risk locations that could not be directly identified by previous methods.

In my research, I have identified a clear correlation between the volume of accidents and the experience time of the driver involved in the accident.

4. In my research, I have identified a clear correlation between the volume of accidents and the experience time of the driver involved in the accident.

I was able to investigate the introduction of a new vehicle type on a given route during the period for the CAF5. This new type of vehicle was gradually introduced on several lines. Due to the physical characteristics of the CAF9, it was only used on route 1, so I did not consider it relevant to carry out such a test for comparison purposes. The tram lines 3, 17 and 19 have allowed a longer time interval to be analysed. Of course, the increase in the number of accidents following the introduction of trams on the route may be due to the fact that car drivers running parallel or perpendicular to the tram have to get used to vehicles with different technical characteristics and that drivers of new trams have little experience of driving this type of vehicle. Therefore, the combined effect of these two factors is likely to increase the number of accidents.

6. SUMMARY

Public transport is about providing mobility for all members of society, but it is also a pillar of sustainable living in cities. Its development is crucial for the livability, further development of cities and the quality of life of people. The main objective is to increase the number of passengers – which is only possible with public transport satisfaction – and at the same time reduce the share of people choosing individual means of transport. However, this requires an assessment of the preferences that lead people to choose public transport. It is important to know exactly which factors are the most important criteria determining the choice of the mode of transport. In other words, improving satisfaction with public transport and developing sustainable urban transport has become one of the most important priorities in urban development.

In the first part of my dissertation I described the processes of urban development and transport development. I have found that changes in the transport system have an impact on the development of the economic activity of a given territorial unit and thus on urbanisation processes. However, at the same time, it can be concluded that the development of a given local area has an impact on the development of the transport system itself.

I have subsequently identified distinctive elements in the urban development of Budapest and highlighted that concentrated phases of urban development (urbanisation, reurbanisation) ensure a more efficient functioning of public transport systems. I have examined the relationship between urbanisation and changes in mobility needs, which predicts an increase in conflicts resulting from insufficient capacity on transport routes, as well as the risk of increased environmental effects that may have negative impacts on urban quality of life. Through literature references, I have reviewed the impact of public transport on the GDP of a region, how it serves to reduce territorial disparities, and how transport development can be an effective tool for regional development. In the context of the European Union's sustainable development goals, I have highlighted the role of public transport and the need to increase its share in the overall demand for displacement.

I have shown that in order to increase the attractiveness of public transport, it is necessary to have an up-to-date knowledge of the expectations and preferences of users and potential users towards the service, in which, according to international literature, transport safety plays a crucial role. I put this in context by presenting the EU and national transport policy context.

In my analysis of the spatial structure and developmental history of public transport in Budapest, I have made a summary proposal for comparing the social, organisational and institutional structure of the different periods, which can be distinguished on the basis of their specific characteristics.

After a general introduction to public services, I narrowed down the scope of my analysis to public transport services, focusing in particular on the role of quality. I then looked at the concept of quality, its relationship with satisfaction and its role in public transport. I have reviewed the main literature on the subject, highlighting the trend of researchers moving away from quantitative research towards qualitative studies.

In the second part of my dissertation, I presented the key databases and research methodologies that I used to approach the assessment of the quality of public transport from two directions: on the one hand, I evaluated primary information collected through a questionnaire survey together with my fellow researchers, and on the other hand, I analysed secondary information in detail through a quantitative study by analysing a factor that is decisive for the assessment of service

quality, the transport safety indicator. Based on the results of the studies, I tested my initial hypotheses.

The hypothesis formulated in the qualitative research on the relationship between transfers and travel time clearly resulted in a more positive impact of transfer-free journeys on the perception of travel time. On this basis, cross-city services on typical travel axes have a justification in terms of perceived quality.

The second hypothesis was based on the assumption that the service for which we pay more is the service for which we expect more. Thus, people who buy a full-price monthly pass have higher expectations, especially with regard to the cleanliness and aesthetic appearance of the vehicles. The responses received confirmed the hypothesis.

At the same time, it is important to highlight that vehicles are one of the areas for improvement that emerged as a result of the empirical research. A new vehicle can both increase aesthetic and cleanliness-related satisfaction, as well as safety-related perceptions of transport safety, and therefore plays a significant role in passenger satisfaction.

In the course of my quantitative investigations, I have come to the conclusion that the role of the transport safety indicator should be emphasised among the quality evaluation criteria for the public service contract of a public transport operator operating in a local area, and I made a practical proposal for this.

I also found that the transport safety risks of the different sectors of an integrated transport system operating in a given local area are different, and the methodology for calculating the transport safety indicator for the evaluation of the service cannot be the same, so I proposed a novel methodology to make the evaluation of service quality specific, taking into account the sectoral characteristics.

As a result of my study, I identified the potential of collecting and analysing public transport accident data in a targeted way to identify traffic conflict points in a given city.

In order to identify the periodicity of the accident data examined by time series analysis, I proposed to investigate the modifiability of the accident black spots detected in each period, and to apply a correction factor for the traffic conditions at the given location.

In identifying the accident black spots for the period under study, I established the lack of active influence of traffic control as a common characteristic.

In my research, I have identified a clear correlation between the volume of accidents and the experience time of the driver involved in the accident, and therefore I suggested assigning novice drivers or drivers with little experience on a given type of vehicle to tram lines with a lower accident risk.

Based on the results of the study, I concluded that the integration of a new transport technology may temporarily lead to a deterioration of the accident rate during the initial period of operation.

7. PUBLICATIONS

Journal articles

1. Khademi-Vidra, Anikó; **Nemecz, Gábor**; Mária Bakos, Izabella (2024): Satisfaction measurement in the sustainable public transport of Budapest TRANSPORTATION RESEARCH INTERDISCIPLINARY PERSPECTIVES 23 Paper: 100989, DOI: https://doi.org/10.1016/j.trip.2023.100989, Scopus: 85180776846, MTMT number: 34500048

2. Nemecz, Gábor (2019): A szolgáltatási minőség mérésének lehetőségei a városi közösségi közlekedési szektorban, [Possibilities for measuring service quality in the urban public transport sector] STUDIA MUNDI - ECONOMICA 6: 4 pp. 24-37., p. 14
DOI: https://doi.org/10.18531/Studia.Mundi.2019.06.04.24-37
ISSN: 2415-9395, MTMT number: 31209236

3. Nemecz, Gábor; Szedlmajer, László (2007): A berlini InnoTrans 2006 kiállítás és a városi közlekedés aktualitásai, [The InnoTrans 2006 exhibition in Berlin and urban transport news] VÁROSI KÖZLEKEDÉS 57: 2 pp. 74-79., p. 6
MTMT number: 31146203

Book excerpt

1. Nemecz, Gábor; Szedlmajer, László (2016): Megújulás. [Renewal] In: Zsigmond, Gábor (ed.) A fővárosi autóbusz-közlekedés 100 éve. [100 years of bus transport in Budapest.] Budapest, Magyarország: Műszaki Könyvkiadó, BKV Zrt. (2016) 264 p. pp. 183-257., p. 74, ISBN 9789631666076, MTMT number: 31128955

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2. Nemecz, Gábor (2020): Városi kötöttpályás közlekedésfejlesztési projektek területfejlesztő hatásai. [Spatial development impacts of urban rail transport projects.] In: Nagy, László (ed.) City-Rail 2020 Conference. Budapest, Magyarország: Budapesti Közlekedési Vállalat Zrt., Közlekedéstudományi Egyesület (KTE), 167 p. pp. 34-43., p. 10, ISBN 9789638121905; 9789638121912, MTMT number: 31359675

3. Nemecz, Gábor (2020): Geography and city structure of Budapest and their effects on Public transport services, In: Horváth, Bálint; Földi, Péter; Zsombor, Kápolnai; Antalik, Imrich (eds.)

International Conference of Economics PhD Students and Researchers in Komarno: Conference Proceedings. Komárno, Szlovákia: Janos Selye University, 213 p. pp. 148-157., p. 10, ISBN 9788081223488, MTMT number: 31359667

4. Nemecz, Gábor (2020): How to define optimal technical conditions of an economically sustainable, urban public transport fleet. In: Horváth, Bálint; Földi, Péter; Kápolnai, Zsombor (ed.) VI. Winter Conference of Economics PhD Students and Researchers: Book of Abstracts Gödöllő, Hungary: Szent István University, Doktoranduszok Országos Szövetsége, Közgazdaságtudományi Osztály, 128 p. pp. 93-93., p. 1, ISBN 9789632698953, MTMT number: 31359662

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7. Nemecz, Gábor (2019): Budapest gazdasági átalakulása a rendszerváltást követő két évtizedben. [The economic transformation of Budapest in the two decades following the change of regime.] In: Horváth, Bálint; Kápolnai, Zsombor; Földi, Péter (ed.) V International Winter Conference of Doctoral Students and Researchers in Economics: conference proceedings. Gödöllő, Hungary: Doktoranduszok Országos Szövetsége (DOSZ), 714 p. pp. 442-450., p. 9, ISBN 9789632698434, MTMT number: 31135112

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