

**THESES OF DOCTORAL (PHD)
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**PÉTER DÁNIEL BORBÁS
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**Quality assessment of community transport
operators in local spaces**

Theses of doctoral (PhD) dissertation

Péter Dániel Borbás

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Name of doctoral School: Doctoral School of Economic and Regional Sciences

Discipline: regional science

Head of Doctoral School: Dr. Zoltán Lakner
Professor, Doctor of Agricultural Science, Doctor of the Hungarian Academy of Sciences, MATE Department of Agricultural Business and Economics

Supervisor: Dr. József Káposzta
Professor, Doctor of Economic Science
MATE Institute of Rural Development and Sustainable Economy

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Head of School's approval

.....
Supervisor's approval

1. BACKGROUND TO THE WORK AND OBJECTIVES

For centuries, economic and social events were confined within the city boundaries, and any movement beyond, typically covering short distances, was managed by harnessing human or animal power. Space, however, began to expand due to technological development, with the role of cities and their immediate surroundings transforming through economic and social functioning and cooperation, and population concentration and spatial expansion beginning to take place, bringing about changes in the volume and characteristics of passenger transport as well. In 2018 1.7 billion people, 23% of the world's population lived in cities with millions of inhabitants, and their share is expected to reach almost 30% in 2030 (United Nations 2018). The expansion of cities has been accompanied with a significant increase in mobility needs within the city boundaries and even between agglomerations and urban centres, with a growing emphasis on local transport issues.

The role of social mobility in the life of cities has become crucial, but now it is clear that the impact of dynamic progress on sustainability and liveability must also be considered. The approach to spatial development strategies is currently shifting, with a preference for community forms and solutions over individual motorised solutions in European urban areas in the interest of liveability and sustainability, and a focus on developing and encouraging the former (particularly by promoting means of transport with lower specific emissions, such as rail) by the local authorities. In order to meet the EU and domestic mobility strategy objectives, developing public transport at international, national and local level is essential, including the extension of rail networks, which, due to considerable infrastructure requirements, are resource intensive but can meet significant transport needs at relatively high speed (using separate tracks or adequate level of priority), with moderate environmental impact.

Public transport is a solution for those who are unable to use personal motorised transport because of their situation (for example, they are unable to drive due to their age or health condition), and for those who choose to do so (even though they have their own car). *Community transport* (or public transport) can be operated as a public or market-based service, typically with predetermined routes, timetables and stops. In Hungary local community transport is a public service provided by the municipalities on a voluntary basis, while the Municipality of Budapest is required to carry out this task mandatorily (Act XLI of 2012 on Passenger Transport Services). Public transport services are typically provided by (one or more) Public Service Provider(s) engaged by the Transport Organizer (the authority responsible for the service or a delegated body acting on its behalf) primarily to meet the basic needs of the population as well as to serve

general economic interests on a contract basis for a specific period and a designated area of operation in a way accessible to all stakeholders.

Particularly in the urban areas, the declining role of community transport has major negative consequences, such as increase in congestions and road accidents, parking difficulties, and higher carbon emissions. Therefore, it has become an important objective for local and central governments to motivate people to use community transport instead of cars. Since fares cannot be reduced due to high costs and losses, a realistic solution to increase the use of public transport is to improve the quality of service (Duleba 2010). The quality of transport services has an important role in attracting and keeping passengers. Moreover, the availability of resources has declined with recent macroeconomic developments, influencing quantitative capacity expansion in a negative way and reinforcing the need to focus on (and improve) the qualitative service elements instead.

Service quality is concerned with the aspects of public transport that directly influence passenger satisfaction, expressing the overall measured or perceived performance of service from the users' perspective. As in practice the Transport Organizer (or its agent) is the organisation that is responsible for the service, it can be assumed that the expectations expressed by it will cover some of the user needs as well. The requirements of the Transport Organizer ordering the public service are essentially defined in public service contracts which specify not only quantitative requirements but also the relevant quality criteria, a major aspect of which for users is passenger comfort.

In my dissertation I will discuss the quality elements of public transport services in cities, especially the specificities of the related public service contract requirements. The initial idea was that due to resource constraints it is necessary to focus on quality improvement rather than on quantitative service expansion to achieve the key objective of urban development, i.e. to increase the share of community transport by meeting mobility needs in local spaces.

The practical objectives of my research include the development of an evaluation methodology and the analysis and improvement of the qualitative components of existing public service systems.

1.1. Justification and relevance of the topic

My daily work concerns the operational issues of local public transport that are based on the current public service contract system. In terms of ensuring operating conditions, the efficient use of resources has become an increasingly important issue, with a fundamental impact on both the quantitative and qualitative characteristics of public service. The fact that the assessment of qualitative characteristics by users (passengers) is mostly based on subjective elements, while the contracting authorities are constantly seeking to make their evaluations increasingly objective and measurable is a key issue in the provision of service.

This kind of duality makes the development of an evaluation system and the identification of an appropriate methodology difficult and therefore my research is partly focused on analysing the complexity of the issue.

The public service contract on which the public transport system operating in Budapest is based defines expectations and levels of adequacy for service quality which, however, must be reviewed from time to time. Also, from a practical point of view, it is necessary to explore the probable effects of the periodically changing boundary conditions of operation with regard to the criteria established. In this regard I believe that the conclusions drawn and the proposals made on the basis of my research will provide methodological and practical support for a substantive review of the contract regime.

In the course of my study I focused mainly on community transport in Budapest, and particularly on the public service characteristics of the road rail (tram) sector, where the composition of the rolling stock has changed in recent years with the acquisition of new vehicles and is expected to continue to change in the coming period, with a positive effect on service quality components (service performance, passenger comfort).

1.2. Objective of the paper and research questions

The overall objective of my dissertation is to highlight the importance of quality in local public transport services in order to promote sustainable development, improve liveability and reduce environmental impacts, as well as to analyse and support the quality assessment of urban passenger transport services in general, and specifically the contract system for the provision of community transport service in Budapest through practical methods and proposals. The findings of my research may contribute to the establishment and further development of evaluation systems that are better suited to the current requirements and consequently are more appropriate for the identification and determination of the points and directions of intervention that can help improve the performance of public tasks.

I also formulated a number of sub-objectives defining the directions of my research:

- ✓ Developing a methodology to analyse the standard international indicators describing the productivity of typical public transport activities in local spaces to provide a basis for service development interventions through an objective assessment of resource efficiency.
- ✓ Due to capacity constraints, applying a scientific method for prioritising and weighting the characteristics used for the assessment of service quality, the results of which may influence the planning and scheduling of service development interventions.

- ✓ Developing a comprehensive, quantitative evaluation system for the objective assessment of the performance of public transport service providers operating locally in order to ensure comparability over time or space.
- ✓ Reviewing the contractual quality requirements for public transport services in Budapest with respect to the content of the indicators used, the factors affecting their development, and the methodology for evaluating compliance.
- ✓ For the public service system operating in the capital city, determining the expectations of the Transport Organizer for the next evaluation period is an important issue. Based on this, developing a methodology to analyse and model the impact of changing operating conditions on the compliance range of quality indicators.

In connection with my objectives I sought to answer the following research questions:

Q1: What types of indicators can be used for comparing the efficiency of public transport services in different cities?

Q2: In establishing the priority ranking and weight of the components of the quality indicator system for local public transport, to what extent is the public service status of the participating experts determining?

Q3: What is the role of comprehensive and objective assessment in relation to the qualitative components of local transport service performance?

Q4: Is there a clear correlation between passenger comfort rating and the methodological characteristics of Transport Organizer inspections?

Q5: How can we model probable developments in the selected quality criteria for public transport service in the case of changing vehicle stock composition (e.g. service loss indicator, vehicle conformity indicator from a technical, aesthetic and passenger comfort perspective)?

1.3. Research hypotheses

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

H1: Basic operational data alone are not suitable for assessing the efficiency of local public transport systems, but the ratios derived from them allow objective comparisons to be made.

H2: There are significant differences in the priority rankings of the quality elements of public transport service depending on the point of view of the Transport Organizer and the Service Provider.

H3: The use of a multi-factor decision analysis method allows a comparison of service performance over different periods through an integrated assessment of quality criteria with different intensity and compliance rating.

H4: There is a statistical correlation between the vehicle conformity indicator defined as part of the quality requirements of the Budapest public transport service contract from a technical, aesthetic and passenger comfort perspective and the type of assessment, the spatial location of the inspected lines and the types of vehicles concerned.

H5: Changes in the composition of the assessed vehicle stock have a quantifiable impact on the vehicle conformity indicator defined as part of the quality requirements of the Budapest public transport service contract from a technical, aesthetic and passenger comfort perspective and the service disruption indicator used for measuring service performance.

2. MATERIAL AND METHODOLOGY

Based on the objective of my dissertation, I have looked at the problems of assessing the quality of public transport. From a methodological point of view, I have identified a management issue related to the specific topic in line with the operational practice and transformed it into a research problem. I have drawn upon secondary information typically available in connection with the operation of a public transport service provider.

2.1. Structure of the paper

As for the **structure** of my dissertation, the paper begins with a literature review, followed by a description of the material and the methodology used and the presentation of my findings, where the conclusions and the resulting recommendations provide a framework for the logical structure of my research on the selected topic.

The **literature review** begins with a presentation of the role of public transport in relation to local spaces. Here, by reviewing the relevant literature (e.g. European Environment Agency, 2019; Szalmáné-Bíró, 2022), I will demonstrate that in order to address the pressing issue of fast-growing urban mobility needs it seems appropriate and necessary to favour public transport in urban and transport development decisions, as it is a more environmentally friendly solution than the use of individual cars, and it can contribute to the socially accepted objectives of sustainable development and liveability. In this context I will analyse the current strategic documents on transport policy for the European Union and Hungary (in particular, European Commission 2011, BKK Zrt. 2020) that clearly include the objective of increasing the share of public transport. By reviewing the relevant literature (e.g. Agócs 2013, Takács 2020), I will present the history of the development of urban rail networks, followed by the development directions and current trends of road rail (tram) service (including UITP 2019) considering that in view of the mobility problems of local spaces it appears as a possible means of achieving the transport policy objective mentioned.

As another aspect of the literature review, I will focus on public service systems, and particularly on public transport activity. A significant portion of local transport functions is necessarily covered by public service, the operating conditions and requirements of which are reflected in the agreements established between the relevant contracting body (typically municipality) and the service provider engaged (Regulation (EC) No 1370/2007, Act XLI of 2012).

The next part of the literature review is concerned with the role of quality. Based on the sources reviewed (e.g. Seco-Goncalves 2007, Moslem-Celikbilek 2020, Dell'Olio et al. 2011) it can be concluded that the improvement of quality,

and particularly its components critical for users, has become an important issue in the context of enhancing the role and attractiveness of public transport. From this aspect I find it important to analyse the literature sources relating to passenger comfort (including in particular: Bodnár-Csomós 2018, Imre-Celebi 2017, Ndoh-Ashford 1994). Finally, I will explore the current phenomena influencing service quality.

Due to the trend of decreasing resource capacities, efficiency is now a common expectation for public transport services expressed by the contracting authorities, therefore the concept of efficiency will also be discussed (some relevant sources: Kökényesi-Andriská 2002, Solt 2008).

Next, I will analyse the dilemmas of service quality assessment and present the **information sources, databases and scientific methods** that will be further considered and applied in my research.

My **concrete research** is based on the theoretical foundations of the literature review, with their **results summarised** in the dissertation, and concluding the chapter by **examining the validity of the proposed hypotheses and summarising the new scientific results**.

In the **next part** of my paper I will draw on the findings of the study to put forth my **main conclusions** and the related **proposals**. Finally, I will **conclude** my dissertation with a summary in English and Hungarian.

2.2. General research methodology and databases used

With regard to **research methods**, the research discussed in my paper primarily followed a quantitative strategy. During this I selected a data collection method providing figures to confirm (or reject) the assumptions made on the variables of the subjects. In the course of my examinations I sought to draw conclusions and assume correlations using the database of values, indicators and indexes collected in connection with the research topic and processed with mathematical methods. With respect to a number of other subtopics, a correlation strategy was used to explore the existence of possible relationships (e.g. for specific criteria) and their direction and strength. Based on the objectives set, my research falls into the category of applied research as it was aimed at acquiring knowledge and expertise that can help develop new methods to be used in practice, and also to improve existing procedures and services.

According to the applied data sources I conducted a secondary research on my dissertation topic as new knowledge was created by comparing and analysing existing and well-documented information and data. As part of my work, I regularly use the corporate databases as an essential source of periodic information on the service activities of BKV Zrt. (SAP, ForTe), where the available corporate statistics and statements proved helpful during the data collection process. In addition, factual data from the public service contracts

relating to the evaluation of service performance and the results of the transport organizer's assessments going back several years were also used as a basis for certain analyses. In terms of time dimension, the analyses included in my paper included both cross-sectional and longitudinal research components.

With regard to scientific understanding, I primarily relied on inductive reasoning, where the process started with the observation and systematisation of empirical facts, followed by analysis and conclusions. My hypotheses were confirmed or rejected based on the relevant conclusions. For certain parts of the study deduction was used to test the practical implementation of the general findings.

2.3. Evaluation of the quality of public transport

My basic approach is that, given the different priorities of the individual actors (transport organizer, user, service provider, other transport stakeholders), the quality of service can be assessed using a multivariable approach, the basic information for which can be produced through detailed status assessment.

This requires an evaluation system that takes into account pre-defined performance indicators and is suitable for the complex assessment of public service performance over the period examined, also allowing for comparability of service quality. At the same time, I assumed that the service requirements stipulated by the Transport Organizer also take into account the quality criteria expressed by the users (passengers), to be reflected in the set of indicators for assessing the performance of public service.

The need for performance assessment is also reflected through a different approach, as the Transport Organizer would like to be informed from time to time about the weaknesses of the public service, and the service elements to be improved. Evaluating the different aspects of community transport helps to highlight areas of underperformance in order to improve service levels and thereby attract additional users (De Ona et al. 2016).

2.4. Basic operational data on urban transport networks

With respect to the evaluation method to be used for transport service providers, the expectation to be able to clearly assess the adequacy of the activities of the companies concerned is well justified. The fundamental problem is that it is difficult to define compliance (qualitative) categories for a future period in advance, however, there are a number of methods that can help establish them.

Although basic operational data can be used to characterise the size, extent and volume of the tram capacities of cities, they alone are not, or only to a limited extent suitable for qualitative and efficiency analyses and comparisons. To identify possible competitive advantages, it is impractical to compare the levels

of public transport service operating in cities only with themselves, but instead comparative analyses should be carried out, for example on the efficiency of operation, which requires the comparability of typical data.

The analysis can be based on ratios derived from basic data describing transport service or operating activity along international standards. The ratios derived from appropriately defined basic parameters can be used to assess efficiency and to evaluate transport services from a given point of view. The following ratios (indicators) have been analysed:

- ✓ operating staff per 1 vehicle put into service (number of persons),
- ✓ peak hour vehicles released as a percentage of total vehicle stock (%),
- ✓ direct costs per capacity kilometre (EUR),
- ✓ useful passenger kilometres as a percentage of capacity kilometres released (%).

In order to calibrate a "normal" or acceptable level, the so-called interquartile range indicators have been used. The lower and upper quartiles capture 50% of the total values. The interquartile range has been used to determine the reference range for the adequacy of service quality relating to a given indicator.

2.5. Possible methodology for weighting quality criteria

For the Transport Organizer it is important to know what sort of performance improves user satisfaction and what is the most effective way to increase passenger numbers. Due to resource constraints prioritising interventions is an important issue, therefore the organisations responsible for service should identify the factors that have a greater impact on passenger satisfaction as well as those with lesser importance. This can be used to plan future interventions and to set the direction for service development.

The initial finding therefore is that, from the point of view of the evaluation system, the individual qualitative characteristics are of varying importance, which can be determined by weighting (Pupos-Pintér 2013). According to the method applied in my study, the selected characteristics were ranked by weighting, based on the opinion of transport experts. During the process the opinion of each participant was mapped and the weights corresponding to the preferences of the individual evaluation groups were determined using analytical methods (Duleba et al. 2012).

For the weighting of quality criteria Guilford's method was used. This was based on pairwise comparisons, which allowed the weighting to be shown on an interval scale (Gyarmati 2003). The participating transport experts individually determined the evaluation criteria considered more important by using pairwise comparisons and recorded their results in a preference table.

First I analysed the preferences of the invited experts of the Service Provider (BKV Zrt.), then I added the opinion of the experts of the Transport Organizer (BKK Zrt.) in order to compare the priorities of the two key stakeholders of the public service system.

2.6. Analyses of the quality elements of the public service system

During my work the specificities of the contractual background of public transport service in Budapest are regularly addressed, with the relevant shortcomings and problems duly perceived. My further analyses therefore concerned the quality elements for the local public service provided in the capital city. In the course of these examinations I analysed the Public Service Requirements (SLA quality indicators) established in the Public Service Contract in force between BKK Zrt. and BKV Zrt. and the related Annual Agreements.

2.6.1. Methodology for the overall assessment of the quality elements of the public service system

In practice the assessment of transport service can be based on a multi-element evaluation system. The categorisation of criteria can be interpreted individually, but treating it as a system, a complex assessment can provide the Transport Organizer with a more realistic picture, allowing a comparison of service performance over different periods. Due to differences in the calculation basis, level of value and unit of measurement of the quality criteria, it is appropriate to use an evaluation system that allows comparisons of the factual data measured in different periods individually (as indicators) and of the aggregate values for the periods concerned, as well as determination of the direction and extent of change. Based on this I considered that a multi-criteria comparison method could help provide a complex assessment of the qualitative performance of a given Service Provider (in this case BKV Zrt.) in different periods, even if characterised by multiple qualitative indicators and different levels of conformity.

My analysis was based on the Combinex method – essentially a multi-criteria decision making method – that allows scoring based on a weighted set of criteria, where the sum of the weighted scores of the alternatives provides the final ranking (Michelberger-Beke 2020). This method was used for the weighted aggregation of the factual values of the contract indicators characterising the quality of the public transport service of the Budapest tram network, and to determine aggregate values for different periods. The evaluation parameters constituting the assessment criteria were taken from the Public Service Contract in force between BKK Zrt. and BKV Zrt. and the Public Service Requirements (quality indicators) established in the related Annual Agreements.

2.6.2. Analysis of factors influencing the adequacy of service quality

In the statistical representation of reality, defining the criteria is of primary importance, i.e. the evaluation criteria by which the statistical population can be broken down. In terms of criteria, my study focused on the analysis of two of the quality indicators that make up the SLA system under the Public Service Contract, namely service disruption and vehicle conformity from a technical, aesthetic and passenger comfort perspective.

2.6.2.1 Time series analysis

Monthly and yearly data according to vehicle types are available for both the Vehicle Conformity and the Service disruption indicators (BKV Zrt. tram sector, 2018-2021). For both the transport organizer and the service provider, the analysis of periodic performance data is an important element in order to draw conclusions on trends, necessary interventions, and even methodological changes. As the sequential nature of the observations provides important information, it was considered appropriate to use time series analysis in order to examine the evolution of service quality indicators. I applied the time series data to specific periods (calendar years), as for the purposes of my study, analysing them for a single point in time would have been meaningless.

I used moving average trend calculation that is statistically interpreted as a method of assigning a trend value to the ‘t-th’ element of the time series by averaging certain elements surrounding it (Hunyadi-Vita 2002).

2.6.2.2. Independence test

With regard to the transport organizer’s evaluation methodology applied to the SLA indicator for vehicles from a technological, aesthetic and passenger comfort perspective, initially I assumed that certain characteristics (type of assessment, spatial location of the lines concerned, type of vehicle) have a dominant influence on the outcome of the transport organizer’s evaluation and therefore affect the assessment of quality adequacy.

According to contractual stipulations, the type of assessment can be either line or site related. As line inspections are carried out during the day, typically several hours after the vehicles have been released, initially I assumed that their results would be less favourable than those obtained for a pre-service inspection carried out on site (depot), due to the fact that the cleaning of vehicles may appear more effective at this stage.

The scope of lines covered by the assessment is limited and determined by contractual timetable stipulations (at the time of the assessment there were 35 distinguishable numbered routes on the Budapest tram network, including secondary service). I assumed – and therefore analysed – that the spatial location of the lines influenced the quality indicators relating to passenger comfort and aesthetic condition. I grouped the tram lines according to urban centre, inner

periphery, outer periphery and cross-city categories (with each numbered line belonging to only one set).

Previous experience showed that new or newish vehicles (CAF, Combino) were typically less likely to draw aesthetic or damage-related complaints from the Transport Organizer than older types and therefore considered it worth examining whether there was a correlation between evaluation results and vehicle type.

During the analysis I examined whether there was a relationship between the criteria and the conclusions which could be drawn (independence test). For the variables where independence could not be statistically verified I used Chuprov's association coefficient to characterise the closeness of the stochastic relationship (Hunyadi-Vita 2002). The statistical operations were performed using Microsoft Excel.

2.6.2.3. Decision preparation and modelling for economic systems

Public service activity is fundamentally determined by the content and elements of the requirements drawn up by the transport organizer for task performance. These are manifested in the public service contract which, by its very nature, defines the primary conditions of operation for the long term. In addition, as part of the contractual framework, annual agreements can be used to establish current requirements for the individual segments in accordance with the content of the basic contract. This provides an opportunity for the transport organizer to enforce periodic expectations (annual performance and quality requirements, and the related financing level and rules) and to take into account current changes in the particular area of operation. However, I also found that in the preventive preparation processes relating to service quality directives the method of establishing the reference range for adequacy for the next period (calendar year) was not well substantiated, which indicates a management problem. The most characteristic development is expected from the change in the composition of the rolling stock of BKV Zrt. anticipated again from 2024 similar to recent years, and although the overall performance level will not decline, the number of vehicles will be slightly reduced (with the acquisition of new vehicles and the simultaneous withdrawal of older types), raising a question as to the direction and extent of changes in contractual qualitative characteristics that can be expected as a result of structural transformation.

The statistical background of the *model predicting the changes of the service disruption indicator* relies on the number of journeys required per type and the service disruption data according to cause. The model uses the number of vehicles put into service (and their composition by type) as input, and the data on the number of planned and missed journeys as specific values per vehicle provide the basis for calculation.

To predict the impact of stock changes, it seemed appropriate to create another mathematical model to calculate the expected sectoral value of the *vehicle*

conformity indicator from a technical, aesthetic and passenger comfort (TAP) perspective for annual (or even quarterly) periods. In analysing the impact of change in vehicle stock, I assumed that the TAP indicator for a given vehicle type can be interpreted as a distribution ratio, and the sectoral value as the harmonic mean of the data for the years under review by type, weighted by the number of elements.

3. FINDINGS

I carried out the analyses and studies outlined above focusing on the databases described in the previous chapter and using the presented scientific methods. The results of the applied mathematical and statistical methods can be interpreted and analysed on their own, but I sought to use the applied method as a methodological instrument for the parties involved (transport organizers and operators) in public transport services.

3.1. Comparing the efficiency of community transport systems operated in local spaces

I carried out a comparative analysis using the intensity and distribution ratios calculated from the basic data.

In order to assess the appropriateness of the ratios, I determined the mean values (arithmetic averages) against which the operational performance of a given city can be determined as being more (+) or less (-) efficient.

As the operating conditions of local transport can be influenced by various external factors (condition of assets, financing possibilities, willingness to travel, etc.), I considered it more realistic to establish a reference range for determining adequacy (with values outside this range indicating particularly high or low efficiency). I took the interquartile range into account to establish the reference range. For their properties, limit values Q1 and Q3 were calculated by taking into account the appropriate sequence numbers.

With the interquartile range defined, a simple rating system (categorisation) could be developed with regard to the given criteria:

- ✓ values between Q1 and Q3 considered as average (0),
- ✓ values below and above Q1 and Q3 considered below average or above average in terms of efficiency (deciding the category to be considered more favourable depends on the interpretation of the indicator).

Overall, the examined indicators showed which of the selected city(ies) had a tram network operating with a high level of efficiency and which areas of service were inadequate in some respect (in the period examined).

Justification of my first hypothesis: Looking at the content of the literature, it became clear that efficiency is typically a relative concept, which can be expressed by indicators defined on the basis of ratios. In the course of my study I presented a possible methodology for comparing public service performance in different cities. The basic purpose of the analysis was to help define the measures required to improve productivity by comparing the operational efficiency of different cities in a given period. With respect to the example presented in my

analysis, I demonstrated that basic data alone are not sufficient to determine efficiency, as it can only be assessed objectively through ratios. For example, in the case of Arad, the number of people employed in the tram sector was the lowest among the cities examined, but as a ratio expressed per vehicle, it appeared to be the least efficient.

Overall, I found that for a comparative analysis of the efficiency of public transport systems operating in different locations basic data alone are not suitable but only the ratios derived from them, and therefore I consider my first hypothesis confirmed.

3.2. Determining weights for the quality criteria of the evaluation system

As a starting point for using the method, transport experts from BKV Zrt., the operator of the service were invited. The experts individually determined their preferences by comparing 13 selected pairs of quality characteristics and recorded their results in a preference table.

The resulting weights indicated that, according to the opinion of the experts of the operating company, safety considerations were of primary importance, but network characteristics (Punctuality and Reliability, Network Size, Frequency, Travel Speed) were also important. The relatively high weight of the price/quality ratio indicates the sensitivity of the issue of fares, while the condition of vehicles and stops and their features, and the tariff system on offer were less important from the point of view of service quality.

Next, I looked at the differences in the order of preference resulting from the involvement of experts from the Transport Organizer (BKK Zrt).

The results showed that safety considerations appeared to be the most dominant elements for both companies (safety on board, safety at stops and stations).

It is noticeable that in the opinion of the experts of the BKK Zrt that is also responsible for public transport organisation tasks in the capital city, the quality aspects relating to timetable structure and capacities (Frequency, Available Capacity) and those included in the public service requirements (Internal Cleanliness and Condition of Vehicles) were more dominant and therefore had a greater weight than for the experts of the Service Provider.

Justification of my second hypothesis: The analysis performed with Guilford's method based on pairwise comparison demonstrated that, given the limited availability of capacities, the objective of using a scientific method to prioritise and weight the characteristics for assessing service quality can influence the planning and scheduling of service development interventions. The results of the analysis demonstrated that safety features were the most dominant in the

preference ranks established by the experts of both the Service Provider (BKV Zrt.) and the Transport Organizer (BKK Zrt.), and that the two lists did not indicate any significant difference in the ranking of components.

Overall, I do not consider my second hypothesis to be justified as the results of my analysis show that there is no significant difference between the ranking of the most and the least dominant quality aspects from the perspective of the Transport Organizer and the Service Provider given their almost identical priority rankings.

3.3. Overall assessment of the quality of public service performance

With regard to the evaluation of service quality, I considered the use of a uniform and homogeneous scoring system necessary because it ensures the comparability of factual values relating to indicators with different bases, values and dimensions. Meaning of scores: the extent to which the individual evaluation parameters contribute to achieving the service objectives and meeting the transport organizer's needs. For the assessment of the quality attributes I took into account how the adequacy of a specific indicator is influenced by the variation of scores (whether a higher score is associated with a better or worse rating). Based on this, I distinguished between linear and inverse intensity ratios expressed by different mathematical functions.

I calculated the scores for the evaluation criteria and periods based on the formulas established for the linear and inverse intensity indicators. From the aggregate scores I was able to determine the period in which the individual indicators of service quality performed particularly well. Looking at the unweighted average scores for the examined period I found that the overall trends for Service Disruption and Traffic Safety were more favourable than for Punctuality and Passenger Comfort.

In previous calculations the individual evaluation criteria and factors were given the same priority, however, there are differences in the importance and role of the individual quality indicators depending on the users or transport organizers' perspective, so it is advisable to consider them with different weights in the evaluation system. The transport organizer responsible for the service may also express its public service objectives to be achieved by considering a weighting system assigned to the individual indicators. The examined model was based on the Public Service Contract in force between BKK Zrt. and BKV Zrt., which reflects the transport organizer's expectations with regard to quality criteria. In the model the weights for the quality indicators were determined using the so-called RP number as the product of two factors, i.e. transport organizer preference and the probability of occurrence. In the model the absolute values of the calculated weights are insignificant, as only their relative magnitude (ratio) is relevant. The

weights calculated with the RP numbers based on the transport organizer's criteria showed that "Service Disruption" was of high priority.

I "corrected" the periodic scores of the factors with weights based on the transport organizer preferences. The aggregate of the rating values (weighted scores) for the quality criteria characterise the performance of the Service Provider.

Justification of my third hypothesis: My analysis was based on the Combinex method, essentially a multi-criteria decision making method for aggregating the ratings of alternatives according to different criteria. The results obtained through this method provide a realistic picture of the performance of the Service Provider (BKV Zrt.) with regard to the contractual quality indicators and therefore are suitable for a systematic overall rating of the public service activity of the engaged Service Provider from the perspective of the Transport Organizer.

Overall, I have successfully adapted and applied a multivariate research methodology that has allowed me to evaluate and compare the qualitative performance of a public transport service provider operating in a given local space over different periods in an objective and integrated way, and therefore I consider my third hypothesis confirmed.

3.4. Analyses using SLA indicators of service quality

3.4.1. Time series analysis of the service disruption indicator

The evolution of the indicator is determined by the operator's "attributable" service disruption (as a percentage of the planned number of journeys), with components including service disruption due to technical failure or staff shortage as defined in the contract. The similarity of the time series shows that the sectoral trend for the indicator in the given period was clearly determined by technical failure.

Compared to the sectoral value, it is apparent that the recent acquisitions (COMBINO, CAF) had much better service disruption rates (with lower values). In terms of vehicle stock and performance, both the number and the share of new trams increased over the years, contributing to improving sectoral figures. Using a centered moving average with six elements I analysed the trend of the time series and found that there was a noticeable sector level improvement in the examined period until 2021.

The impact of the seasonal component is indicated by the increased volume of technical failure induced service disruption due to more extreme weather conditions in the winter and summer months, while it remained more balanced in the spring and autumn periods.

Based on the data for the years examined, the SLA indicator was less affected by staff shortage related service disruption, although the shortage of drivers has

been a typical feature for the tram operation of BKV Zrt. for years. The analysis indicates another seasonal effect: in certain periods higher annual leave and sick leave rates caused periodic surges in the percentage values. Again, using a centered moving average with six elements I examined the trend of the time series and found that there were no significant sector level changes in the period 2018-2021.

3.4.2. Time series analysis relating to the vehicle conformity indicator from a technical, aesthetic and passenger comfort perspective

The condition of public transport vehicles is assessed through line or site related inspections. The methodology for line and site inspections has varying characteristics, for example, while the former may cover vehicles belonging to multiple routes and sites, the latter concerns trams running from a single site (tram depot). As for the share of non-conforming vehicles, the figures showed that, although the difference was still significant in 2018 (25%), in recent years (since 2019) there has been a difference of only 3-4% between the two types of inspections.

According to contractual stipulations, the conformity indicator is expressed as a ratio calculated from the number of vehicles with a "pass" rate in a given category compared to the total number of inspections. It is striking that certain conformity groups have consistently reached 100% or very similar values. Overall, according to the actual inspection results, inadequate quality performance was found in categories D1 (Damage, Bodywork) and E1 (Graffiti, Upholstery) ($x < 95\%$ as agreed). It is typical for these categories that the repair of external physical damage to the vehicles generally requires considerable financial resources (replacement of glass or bodywork elements, varnishing) on the part of the Service Provider, which clearly falls outside the scope of daily cleaning and maintenance activity. However, for the E2 category, which concerns the cleanliness of the exterior and interior of the vehicles and is the most relevant for passenger comfort, service performance was relatively high and consistent (96-98%).

I also considered it practical to look at the yearly figures by vehicle type. Based on the data, the assessments carried out on new, newish and modernised vehicles (CAF, Combino, KCSV7, T5C5K) indicated higher levels of conformity year on year compared to the non-modernised "traditional" types (ICS, T5C5, TW6).

3.4.3. Correlation analyses relating to the vehicle conformity indicator from a technical, aesthetic and passenger comfort perspective

The assumed correlation between compliance with the SLA and certain influencing factors and evaluation characteristics was analysed using the independence test method for the vehicle TAP indicator (influence occurs when the variables are not independent).

Justification of my fourth hypothesis: The assessment of the vehicle conformity TAP indicator was based on the results of transport organizer evaluation (in a periodic breakdown, but with annual financial assessment). The results of the performed analysis confirmed no correlation between conformity of the indicator and the type of evaluation (independence of the variables was shown in the period from 2019, so conformity was not substantially affected by the type of the evaluation, i.e. whether line or site related). However, based on the correlation analysis

performed, the assumption that compliance with the specific indicator is influenced by the location of the inspected trams' routes (urban centre, inner periphery, outer periphery, cross-city) was found to be correct. There was an even stronger correlation between the type of vehicles inspected and their TAP conformity, so the evaluation results were strongly influenced by the part of the rolling stock that was subjected to inspection.

Overall, I found a clear statistical correlation between the TAP conformity indicator of vehicles on the one hand and the spatial location of the lines and the type of vehicles inspected, but the assumed correlation between conformity of the indicator and the type (location) of evaluation was not confirmed (independence of the variables was shown), based on which my fourth hypothesis was only partially verified.

3.4.4. Model for predicting the service disruption indicator value

The compliance limits of the SLA indicators are subject to annual reviews carried out by the Transport Organizer and the Service Provider. In the framework of the annual review, the use of a mathematical model can provide guidance for a reasonable adjustment of the agreed limit values, taking into account, for example, changes in the sectoral composition of the rolling stock as a determinant. From this point of view, the number and distribution of vehicles in circulation by type provide a relevant input for modelling.

Vehicle type is decisive for technical reliability. The time series analysis covering several years indicated that for trams, the newer types (Combino, CAF) show better than the average rates for service disruption and therefore it can be assumed that changing the composition of the rolling stock by increasing the number of newer trams and simultaneously reducing the number of older types released for circulation (possibly at an even higher rate) will have a positive effect on the indicator at sector level. Another important element is that the acquisition of new, modern and more reliable trams will also improve efficiency, allowing the older and less reliable types to be withdrawn at a higher rate.

Modelling was based on the average of the years under review, i.e. 2018-2021 (without adjustment, as a 4-year period is not sufficient for establishing trends), which were used to predict changes in service disruption caused by the two factors

(technical failure and staff shortage) to be analysed. The change can be analysed in relation to the average data.

Based on the average of 4 years of data, a scoreboard was created to record the monthly rates for service disruption (number of failed journeys/number of planned journeys) by vehicle type.

For the years under review I averaged the number of planned and failed journeys per vehicle by type (with the intensity ratios averaged by harmonic mean). Based on these I constructed a mathematical model to predict the expected percentage rate of service disruption taking into account the change in the average release of vehicles by type. The data series calculated with the model show that with the release of new trams increasing and the use of older types simultaneously decreasing, the K value of the sectoral service disruption indicator will consistently improve, although to varying degrees each month.

As an essential result of the modelling, a value acceptable for the Transport Organizer can be predicted annually, which can serve as an input to realistically (and objectively) monitor the impact of changes in stock when determining the contractual SLA expectation levels (Bonus/Malus range). In using the model, it should be noted that it only takes into account the changes in the composition of vehicles released for circulation and is therefore not suitable for predicting the impact of other factors (e.g. mechanical deterioration, modernisation of vehicles).

3.4.5. Model for predicting the vehicle conformity indicator from a technical, aesthetic and passenger comfort perspective

Looking at the composition and evolution of the indicator for the examined period (2018-2021) and analysing the data I found that in fact only a few evaluation criteria had a strong impact on the factual conformity of the qualitative indicator. The rest of the components proved satisfactory in all periods. Based on this I concluded that further in-depth analysis should only be performed on the key factors and that the remaining components could be disregarded. For the passenger comfort aspect of the tram stock, I developed a modified indicator assessment system to ensure a more realistic and pragmatic evaluation.

Completing the time series analysis of the available database, the 5 most relevant evaluation criteria were given new letter codes with corresponding weights. Then a new TAP conformity index was created, which shows the extent to which a given vehicle meets the transport organizer's expectations for passenger comfort, taking into account the primary and modified components.

Next, I converted the factual data for the years 2019-2021 according to the new model. Using the index, I also calculated the modified percentage values of the passenger comfort indicator by tram type and determined the new sectoral TAP value for the years examined.

In relation to the TAP conformity indicator, changes in operating conditions and their impact on conformity are also important. In practice, it typically means changes in rolling stock and the composition of vehicles released (e.g. acquisition of new trams and the simultaneous withdrawal of obsolete ones). The time series analysis covering several years indicated that the compliance rate for passenger comfort was generally more favourable for the new or modernised vehicles, and therefore it can be assumed that changing the composition of the rolling stock and increasing the number of new or modernised trams while reducing the number of older types in circulation will have a positive impact on sectoral performance.

Based on the above I modelled the new TAP values for 2022 and the expected composition of the vehicle stock according to three possible scenarios for the future. The change in stock is practically due to the increasing number (and share) of new CAF trams with the simultaneous withdrawal of older types. My analysis confirmed that the expected future value of the TAP indicator for rolling stock will improve compared to the average of former years due to an increase in the number and share of new and modernised vehicles released.

Justification of my fifth hypothesis: In the course of my research I developed a mathematical model that can be used to forecast on a monthly and annual basis a value acceptable for the transport organizer to serve as a starting point for a realistic (and objective) monitoring of the impact of change in stock when determining the contractual SLA expectations for service disruption rates (Bonus/Malus range). Moreover, as it was suggested by the results of my time series analysis and confirmed by the correlation test performed, the evolution of the TAP conformity indicator is influenced by type, therefore I constructed another mathematical model to predict the direction and extent to which changes in vehicle stock influence the expected value of the quality indicator.

Overall, for both indicators a mathematical model has been applied to predict the expected impact of stock changes on the periodic values of the indicators, based on which I consider my fifth hypothesis confirmed.

3.5. Summary of the new scientific results

1. In my dissertation I developed a methodology suitable to analyse the **standard international indicators describing the productivity of typical public transport activities** in local spaces to provide a basis for service development interventions through an objective assessment of resource efficiency.
2. Using a scientific method, my research provided a practical example for **prioritising and weighting** the characteristics used for the assessment of service quality, the **results of which may influence the planning and scheduling of service development interventions** (given the limited

availability of resources), and can serve as an input for **developing a comprehensive quality evaluation system.**

3. As a result of my research, I successfully adapted and applied a multivariate research methodology that allows the qualitative performance of a public transport Service Provider operating in a given local space to be assessed and compared for different periods. The presented method is suitable to **systematically and comprehensively assess the public service activity of the engaged Service Provider** and to **analyse the role of each component** in the event of change in service quality.
4. I carried out a review of the contractual quality requirements for public transport services in Budapest with respect to the content of the vehicle conformity indicator from a technical, aesthetic and passenger comfort (TAP) perspective, the factors affecting it, and the evaluation methodology for determining conformity. I found a clear statistical correlation between the **TAP conformity indicator of vehicles** on the one hand and the **spatial location** of the lines and the **type of vehicles** inspected, but the assumed correlation between conformity of the indicator and the type of evaluation (whether line or site related) was not confirmed (independence of the variables was shown). Based on the results of the analysis I made practical recommendations to **modify the content elements of the indicator and the methodology of evaluation.**
5. For the public service system operating in the capital city, determining the quality indicators expected by the Transport Organizer in the next evaluation period is a cyclical issue. Through my research I **developed mathematical models** for both the vehicle conformity TAP indicator and the service disruption indicator for measuring service performance which can be used for **predicting the expected impact of stock changes** on the periodic values of the indicators.

4. CONCLUSIONS AND RECOMMENDATIONS

1. Based on the analysis of the operating parameters for the selected cities and the indicators derived from them, the applied method is suitable for comparing the efficiency of public transport services across different urban areas. However, the comparative analysis must take into account the specific characteristics and features that influence service activity in the areas concerned. For example, it seems appropriate to focus on local areas with a similar size of public transport network and operation for which the collection of international benchmarking data can provide appropriate input.

Given the diversity of the external and internal factors and circumstances influencing the service/operating activity, it is advisable to use the reference range method for comparative assessment, where the compliance range is extended based on the data of the analysed elements so that only the truly extreme outliers give rise to further internal analysis (exploration of cause and effect).

Applying the method for objectively assessing resource efficiency based on the collection of benchmarking data will help justify the measures necessary to improve public service productivity.

2. The availability of funding is a major constraint on the delivery of public service, which acts as an incentive for internal and external service providers to improve efficiency, while in determining the directions of development, the level of priority attached to the individual service characteristics is also essential.

Using Guilford's method based on pairwise comparisons and involving transport experts, I determined preference rankings for the selected quality attributes. The method was also used for weighting the specific factors to help interpret the role of the components in an integrated evaluation system.

The results of the analysis demonstrated that safety features were the most dominant in the preference ranks established by the experts of both the Service Provider (BKV Zrt.) and the Transport Organizer (BKK Zrt.) (safety on board, safety at stops and stations). Maintaining and increasing safety is a key transport policy objective that is crucial for the quality of service.

Based on the above, for the practical use of the method I recommend that the group of people invited to provide an opinion should be made up of multiple parties (Transport Organizer, Service Provider, users) to ensure a higher level of authenticity and justification in ranking (and weighting) the quality features, which can ultimately serve as an input for determining the directions of service development and for designing a quality assessment system.

3. The quality of public transport service (SQ) can be approached from several aspects, but the key evaluation factors are typically provided by the Transport Organizer and the users. The Transport Organizer's perspective should take into account and integrate the main expectations of the users as well (in order to improve the acceptance of public transport), however, based on the content of the analysed public service contracts I found that in practice this is rarely done comprehensively, but rather in a simplified way.

Compliance with passenger criteria is generally established on the basis of subjective assessments, while contractual requirements for Transport Organizer expectations are typically based on objective indicators, although with different levels of conformity, intensity and priority.

Considering the above, public transport service in a given period can be assessed on the basis of a complex evaluation system. The categorisation of the relevant criteria can be interpreted individually, but as an integrated system it provides the Transport Organizer with a holistic picture of the service provided and allows a longitudinal comparison of performance over time.

It is also important to note that the relevant studies focus on the assessment of performance by a given (contracted) Service Provider and therefore do not always cover the overall performance of a particular area (e.g. in Budapest the road rail service is operated by one company, while bus services are provided by multiple operators). This in itself poses another dilemma due to the fact that the Transport Organizer is responsible for the local public transport service in the whole area, while in a multi-operator model integrated evaluation is more difficult, and the most obvious tool is a subjective assessment of the quality of service perceived by passengers.

4. The performance of public service tasks (including local public transport) requires a permanent solution from the competent authorities responsible for the provision of service. From the point of view of sustainable functioning of the society, the organisation of the public sector and public services is now a major challenge for public policy and government decision making. This, together with the sustainability expectations of the society, requires a revision and a new approach to quality.

The SLA quality indicators included in the Public Service Requirements of the public service contract in force between BKK Zrt. and BKV Zrt. are adequately defined with a well-developed evaluation method. Furthermore, the quality indicators are given different weights in the financial evaluation reflecting transport organizer preferences. However, some of the indicators defined in the previous version of the contract have been removed from the quality evaluation system (passenger satisfaction index, maximum pollution caused by vehicles, accessibility index, fare evasion rates). This may have been done to adapt to the current financing situation, but in my opinion it is definitely a step back in terms

of social sensitivity, and in meeting and monitoring expectations (even the rate of fare evasion, which has an impact on financial efficiency). In view of the changes in social and proprietary expectations (e.g. equal opportunities, greater focus on environmental and climate protection), it is important to further develop and integrate an adequate evaluation system for the public transport service in Budapest based primarily on objectively assessable quality and efficiency criteria.

5. The service disruption indicator has a crucial role in the SLA system. It has two components: technical failure and staff shortage. Based on the performed time series analyses it was found that the sectoral indicator for service disruption was clearly determined by technical failure, which proved to be dominant over staff shortage. This also implies that in forecasting the indicator, the primary focus should be on the impact of technical features until changes in conditions redefine priorities.

The impact of the seasonal component is indicated by the increased volume of technical failure induced service disruption due to more extreme weather conditions in the winter and summer months over the period examined, while the indicator was more balanced in the spring and autumn periods. A similar trend was observed for service disruption caused by staff shortages (due to fluctuations in annual leave and sickness rates). This clearly indicates that seasonality should be taken into account in planning the annual performance requirements on a monthly basis, thereby refining the predictability of resource needs and improving efficiency.

The changes in operating conditions raise a dilemma with respect to defining the expected criteria for public service performance on a yearly basis; the limit values for the next period are defined in annual agreements as part of a contractual framework (Bonus/Malus system), for which there is currently no scientifically justified methodology. The mathematical model developed in the course of my research can be used for predicting, on a monthly and annual basis, an indicator value acceptable for the transport organizer that can serve as a basis for a realistic (and objective) assessment of the impact of stock changes. When using the model, it should be noted that it only takes into account the changes in the composition of vehicles released for circulation, disregarding the impact of other factors (e.g. mechanical deterioration).

6. Analysing the relevant literature, I pointed out the importance of passenger comfort in relation to the quality of service perceived by users. In my opinion, the conformity indicator relating to passenger comfort is still significantly underrated in the annual agreements concluded as part of the public service contract in force between BKV Zrt. and BKK Zrt. in spite of its role in the attractiveness of public transport.

Based on the time series analysis using evaluation data for the period 2018-2021, it was striking that certain conformity groups that make up the vehicle TAP indicator system consistently reached 100% or very similar values annually, and that in fact only a few criteria had a significant impact on conformity. On the basis of these findings I developed a proposal to modify the components of the indicator.

The transport organizer inspections relating to the vehicle conformity TAP indicator are carried out at randomly selected locations covering specific lines (terminals or en route) or tram depots. On the basis of the results of the performed correlation analysis no correlation between conformity of the indicator and the type of evaluation (whether line or site related) was found. Based on this I propose that the methodology of transport organizer inspection with regard to selecting locations should be revised (the analysis suggests that no distinction by type of location is justified, and the inspection of sites (tram depots) can be simply covered through a random selection of checkpoints).

The performed correlation analysis shows that the conformity of the indicator under consideration is influenced by whether the inspected tram route is in a more or less frequented part of the city. Based on this I find it appropriate that the inspection results be weighted according to the location of the tram routes.

There was a strong correlation between the type of vehicles inspected and their TAP conformity. According to current methodological expectations, the sampling method should be proportional in line with the sectoral composition of the stock by vehicle type. Based on the results of my relevant analysis, I propose a proportional stratified sampling method for determining the evaluation range including the vehicle type as a stratification criterion, but the population should be based on the average number of vehicles in circulation or capacity kilometre performance, rather than stock based. This is because the different types of vehicles contribute to meeting the timetable requirements with varying degrees of availability, transport organizer expectation and specific performance.

During my analyses I constructed another mathematical model that can predict the direction and extent to which changes in vehicle stock influence the expected value of the quality indicator. Again, it should be noted that the model only takes into account the changes in the composition of vehicles released for circulation, disregarding the impact of other factors (e.g. mechanical deterioration).

By using the models, the Transport Organizer's expectations towards the Service Provider can be defined with more specific objectives, leading to an overall improvement in service quality through incentives.

5. PUBLICATIONS

Articles

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4. **Borbás P. D.** (2019): Evaluation of the quality of public transport services. In: Bálint, Horváth B., Borbély A., Fodor-Borsos E., Földi P., Gódor K. A., Kápolnai Zs. (szerk.): *V. Winter Conference Of Economics PhD Students And Researchers*, Book of Abstracts, Doktoranduszok Országos Szövetsége (DOSZ), Gödöllő, p. 28, MTMT szám: 31137940
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