THEORETICAL OPTIMIZATION OF TRAM AVAILIBILITY FOR DAILY SCHEDULES (ROLE OF PUBLIC TRANSPORT AND TRAMS IN BUDAPEST)

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Abstract

The demand for change of location could be emphasised of all the factors of urban development, as it constantly exists in societies even if for different purposes. Mobilisation provides the background of the engine that operates the economy and the society, its role is to realise the movement of persons, goods and services. The key driver of the urbanization, emerging due to the geographic concentration and coordination of economic and social activities, is the changes in the transport system. Physical characteristics of the cities and their changes have a great impact on the development of the transport system. Due to its good environmental impacts, favouring urban rail networks is clearly targeted in urban planning today. With regard to the availability of cars and the schedules, concerning the increased and changing performance requirements, companies that operate tram services seek optimization opportunities primarily in order to reduce expenses. Conformity between transport development and urban development shall be continuously ensured if we wish to prevent fault-lines in the development of the city, however, realization of them has to be matched with the operator's intentions for optimization. Considering these aspects on the long run serves the creation of a better economic, social and spatial structure at the settlement concerned, thereby improving sustainable living standards.

Keywords: *settlement, urbanization, public transport, coevolutive development, optimization*
JEL classification: *M21, R41*
LCC: *HE305-311*

Introduction

The concept of a settlement can be defined in many ways, but the following description may be a satisfactory one: *"A settlement is an autonomous unit, distinct from other elementary spatial organizations. It is an individual habitation of any size or a contiguous group of habitations which serves as permanent residence for people or groups of people and are clearly distinct from other settlements"* (Beluszky, 1973). The systematic operation allows the specialization of the settlements and makes the settlement inhabitable in a way that the three basic functions (work, living, services) are not equally weighted. As we talk about quantity and quality that change over time, it is important to see that the dynamic changes of each element are different. The primary duty of settlements is to provide the society with optimal spatial and technical conditions, while having its own specific features.

It is clear that the presence of rivers, terrain, climate, cultivable areas and construction materials all contribute to the development of a settlement at a given location (geographical determination) (Mendöl, 1963). In addition, however, mobilisation is needed as an opportunity, which, in a stricter or broader sense, depends on survival, work and development in long term.

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The development orientations of cities and transport are already well established, but the continuous examination of their correlations is an essential task.

When researching the main correlations, it is first necessary to determine what the main transport issues and tasks of modern days are. What are the main goals regarding the satisfaction of the demand for change of location, and do customers have any specific expectations? How transport can be interpreted as an extended system, including the main components of society and technology, and what other dimensions affect its development? What is the relationship between urbanization and transport, given that cities are currently in a phase of growth? How do expectations for transport services change as cities keep transforming while ensuring sustainability? The transport structure of modern cities (including Budapest) is based on their spinal network (typically rail-bound), to which, as feeder lines, additional elements (bus) are attached. The operation of the increasingly extensive tram and metro networks include a number of optimization opportunities and dimensional changes that evolve over time. In this study I carry out a theoretical optimization analysis from the operator's view point, aiming sustainability and cost reduction.

Modern day transport issues tasks

Since societies at the end of the last century were characterized by a spatial separation between home and work, it implies a demand for change of location. Depending on the size of the city, such change of location can be distinguished as intra-city or inter-cities, depending on the employment structure of the population. The primary goal for smaller towns with lower population is to provide access to services that are not available locally, while in the cities you need to count with a demand for local, in-town transportation in everyday life. A special type of the demands for change of location is commuting for work purposes from residential areas to industrial suburbs and commuter traffic between the settlements in the urbanization. Today, about 30% of the Hungarian population of working age are commuters. The development of telecommunications and the growth of the service sector together have created and now provide the conditions for work-from-home; however, this is typical of economically better-developed countries at present. A relief on the transportation infrastructure, which is not designed for such a load, and reducing the number of traffic jams may clearly result in improving the everyday living conditions of the society. Ideally, the development / change of transport takes place before or simultaneously with the economic changes in the environment, in which case it does become the real engine, a catalyst for such processes. However, poorly determined development goals that ignore social tendencies and inappropriately distributed sources can become an obstacle for the development processes of a city. Reaching higher standards is ultimately about promoting economic development and balancing territorial disparities. Its development may result in substantial regional development, as its contribution to GDP is also significant (Balázs Mór Terv, 2014).

However, significant costs are implied in the construction and operation of transport systems, which occur at community level and are only partially offset. Often, the circumstances for upgrading technical conditions are inadequate and, as a solution, continued operation is inevitable. However, operation of assets beyond their useful lifespan (Fiáth et al, 2016) is often identified as a hindering effect for economic development as it may generate significant additional expenses. In Hungary, life expectancy of the assets in the transport sector compared to other economic sectors is high; therefore, transport interventions determine the spatial structure, economic characteristics and development potential of the affected territorial unit for a long term. The grounds of development imply a strong emphasis on the government's expectation that the transport system should not slow down economic growth. It is therefore particularly important that transport development objectives should be clearly defined, serve strategic purposes and be well prepared and well founded. The European Union preparatory and decision-making bodies have also recognized this correlation between life standard in cities and the development of the transport system, and have therefore encouraged the spread of sustainable urban mobility plans (Fehér Könyv, 2007-2020). Their purpose is to make more efficient and sustainable use of existing transport infrastructures and to render the quality of the provided services attractive, thereby reducing the environmental impact of the transport system and ultimately improving the quality of life in the area (Nemecz, 2018).

Today, you can still say that the basic operation of a city requires providing available options for motion by creating and operating an appropriately operating transport network that covers the entire city (Figure 1).

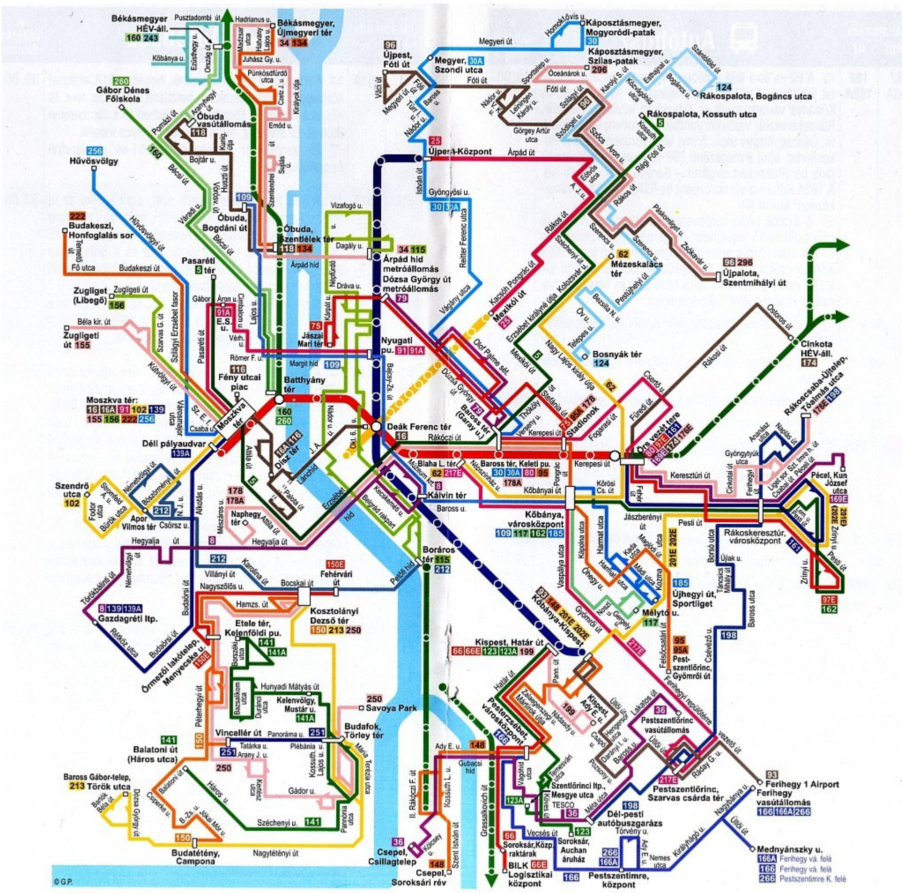

Figure 1: The transport network of Budapest

Source: Budapest.hu, 2016.

Correlation between urbanization and transportation

The consistent finding of national and international literature on urbanization and growth (Bertinelli-Black, 2004) states that there is a coevolutive link between urbanization and transport development. Changes in the transport system (Duranton-Turner, 2012) are the main driving force behind urbanization following the geographical concentration of economic activity, which is greatly influenced by the physical characteristics of cities and their changes. In this sense, not only does the development of the transport system have a significant impact on the geographical concentration of human activities, the structure of built environment, the growth of urban population, the development of the modes of transport has not only facilitated the centralization of economic activities but expanded the city borders, too. For such reasons, the demand for transport services between city centres and suburbanising settlements surrounding the city has also increased (Yago, 1983).

Many authors believe that aspects describing urbanization and physical characteristics of cities, such as the age or size of the cities, are important determinants of urban transport systems. These have a significant impact on the demand for transport services in a given settlement, on the physical organization and pattern of settlements and on the applied modes of public transport and technologies (Buchanan et al, 2006).

Other authors also point out that the appearance, mode, content and system of the institutionalization of public transport and transport development policy have the strongest impact on the development of private and public transport. In this sense, not only the technological foundations and major organizations of the system should be analysed, but also the broader social embeddedness of urban transport systems, i.e. their interactions with the political, economic, technological, social and natural environment.

Furthermore, it is necessary to analyse the operating cost levels from the aspect of sustainability, as their possibility for optimization may affect service standards of the public transport.

The role of trams in Budapest (the city and the public transport)

Over centuries, transport in Buda and Pest had been considered a private matter, and people were not particularly concerned about other opportunities for change of location. Then suddenly appeared a businessman, -–the ferryman –, who offered his rivercrossing services for some consideration, and who was followed by hired cars in the XVIII. Century. Omnibus could be actually regarded as the first element of true public transport in Pest, as it provided a community service between Liget and downtown cafes. The nearly 100-year-long prosperity of omnibus lines, launched in 1832, was influenced by the 1866 horse tramway actually.

At that time, public transport was a huge business in the capital, and nobody thought about the fact it may have any other social role. The first electric tram in 1887 quickly proved its incomparable advantage against the more expensive and slower horse tramway and omnibus. Horse tramways were able to survive until the end of the century, and omnibuses with some insignificant capacity until 1929. From the early 1900s on, trams began to prosper due to the evolution of a competitive environment. As we are considering a very profitable and popular service, it is no wonder that many wanted to take part. The competition was so fierce that indeed tram rails were installed at every available space (Figure 2).

It exceeded the short-term goals of business interests and became the basis for ambitious long-term ideas. Intentionally or not, trams altered the capital and became a defining factor for the next eighty years. Despite the fact that the statement is still true about tramlines being the most determinative factors of the capital's transport system to the extent that with their great capacity and extensive network they are everywhere, it is the underground that gained world-fame, giving grounds to the importance of metro transport in the field of public transport.

At the beginning of the 20th century, the self-development of tram lines had escalated to a level that by 1918 their operation became deficit and was nationalized (Legát, 2018). In 1921, tram companies were wound up, and that allowed BKV's legal predecessor, Budapest Székesfővárosi Közlekedési Rt. (BSZKRT) to form. This period, called the Golden Age by many people, which lasted until 1968, when BKV was founded, coalesceded with the city's most difficult period.

 10.18531/Studia.Mundi.2020.07.03.86-96

The periods of World War II, reorganisation and change of regime clearly left their marks on the transport company, as well. During this period, the transport company and the capital merged and became one where roles – that could not be regarded basic tasks any longer – appeared in the company.

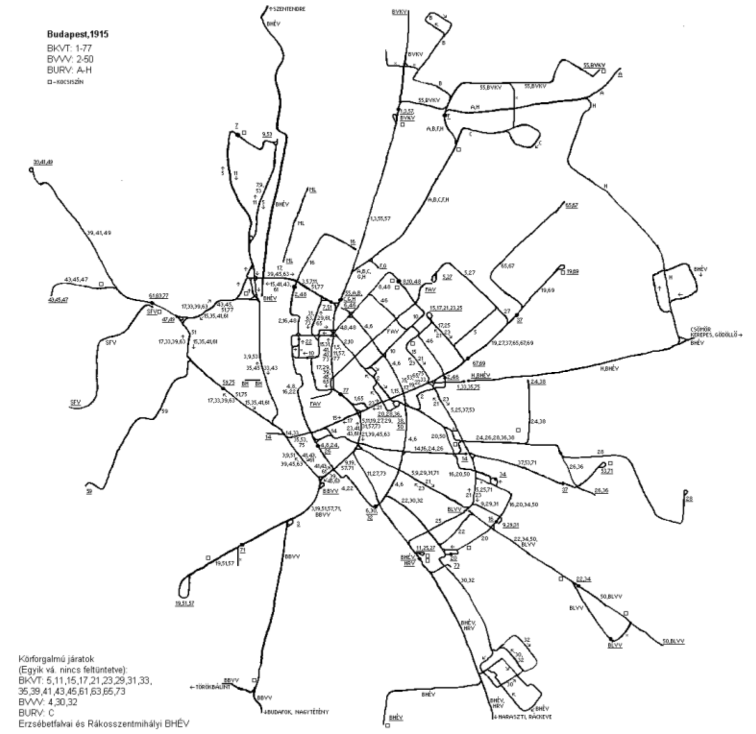

Figure 2: The tram network of Budapest in 1915
Source : villamosok.hu, 2018.

It can be stated that from this period on, the city and transport became coevolutive and continued functioning as a social-technological system. It cannot be said that this relationship worked smoothly from that day on but the importance of the coexistence of urban development and transport development has certainly been recognized.

Cost-optimization and analysation of economic viability of the investments are inevitable parts of the operation, thus, the lack of them may result in situations like the deficit operation in 1918, which triggered nationalization.

Optimization of the availability of tram vehicles with regard to the daily schedules (study)

BKV Zrt. performs its services in Budapest in the framework of a public service contract, ordered by BKK Zrt. Customer expectations of the service are high and the service provider's capabilities are usually taken into account. An order basically sets quantitative and qualitative requirements (low-floor construction, air conditioning...) against the service provider and ignores cost optimization goals.

BKV Zrt. currently operates eight different types of tram vehicles, under various direct place kilometre (ASK) costs (ranging from 2 Ft/ASK to 11.5 Ft/ASK) and two peak loads per day regarding the vehicle availability. During peak hours, approx. 78% of the vehicles are in traffic, and in other hours, this number decreases to 10% (night service).

As the utilization of the most economically efficient vehicles with low place kilometre costs are maximized during peak hours, it is possible to reduce costs by changing vehicles only during the hours with lower performance requirements. During the optimization process, I strive to keep operating costs at the lowest possible level and run low-cost vehicles in the first place, while also improving passenger comfort. In order to quantify the theoretical possibilities, I have examined the annual theoretical cost reduction possibilities using the current schedules. The analyses were based on the current (February 2020) availability targets for tram depots and vehicle types.

This study, being purely conceptual, does not discuss the necessary adjustments of the calculations for the rearrangements of extra service runs, for required infrastructure interventions, and for additional trainings.

Analysis of return on investment was carried out merely on limited quantity in order to be able to estimate the time interval.

I have studied the options for replacements of vehicle types by considering the following average operating cost data for 2018 (Table 1):

Table 1: Average operating costs, 2018

Type	Average direct costs (HUF/thousand place kilometre)	Statistical place
ICS	7,800.26	180
KCSV7	10,247.75	180
Tatra (T2/TK2)	11,559.94	T2-TK2: 180
Tatra (T3/TK3) K=upgraded T3=3 cars	7,341.58	T3-TK3: 270
TW6000-6100	8,760.32	180
CAF5	3,549.42	180
Combino	5,086.03	360
CAF9	2,028.20	360

Source Own, 2020

With regard to operational restrictions on the vehicles and the capacity of trams, I have set up the following three conceptual groups:

- on Line 2 and Szabadság-híd, only ICS and KCSV7 are suitable for use in traffic,
- examining the other 180-seat vehicles, the cost of running CAF5, the upgraded Tatra (two linked tramcars) and TW is lower than the cost of the original Tatra (T2) vehicle,
- vehicles with the highest capacity can run on Lines 1 and 4-6, the operating cost of the CAF9 vehicle is almost the same as of the Combino tram.

Then, based on the above principles, I also examined how to reduce the mileage performance of trams that have higher operating cost while maintaining the timetable structure and the specified number of runs, and still provide the same intervals between services.

On weekdays, the mileage of certain vehicles running during daytime and in the evening hours can be replaced by trams with lower operating cost, operating only in the morning and afternoon peak hours and finishing relatively early in the evening:

- ICS vehicles on Line 19 running only in peak hours can be rerouted to Line 2 during the day and in the evening,
- CAF trams on Lines 1, 3, 17 and 19, that currently operate only in peak hours, can be operated throughout the day,
- Combino vehicles that run only in peak hours on Line 4-6 can be rerouted to Line 1 during the daytime and late evening,
- on Line 1, the mileage performance of the upgraded Tatra trams can be increased and that of the original Tatra vehicles decreased,
- on Line 28-28A, TW6000 vehicles can be used instead of the traditional Tatra trams after the morning peak.

The following table (Table 2) shows how many runs on each Line can be performed by trams with lower operating cost, based on the above statements:

Table 2: Replaceable number of services

Relation	Type	Replaceable number of services
1	**CAF9** instead of Tatra	11
	Combino instead of Tatra	33
	TK3 instead T3	39
	In total	*83*
2	ICS instead of KCSV7	78
3	**CAF5** instead of TW6	14
17	**CAF5** instead of Tatra	15
28-28A	TW6 instead of Tatra	51
In total		**241**

Source Own, 2020.

The proposed changes have been used to calculate the theoretical impacts of the possible changes on the use of costs. It is important to note that several other factors can affect actual costs, so the values in this aspect are illustrative only!

The cost data in the table are calculated based on the actual place kilometre costs and the variable costs and expenses recognized directly in the operation and maintenance of the tram vehicles in Year 2019.

The followings were considered in the calculation:

- as the cost data for CAF5 and CAF9 vehicle types in previous periods are incomplete, I applied the cost data of COMBINO trams for these types,
- in order to avoid the distorting effect of the general repair costs listed in the cost of T5C5 vehicles, I applied the T5C5K unit specific cost data for both types of the Tatra trams in the calculation,
- due to the significant cost of ICS tram repairs that are expected in the near future, I have not taken into account replacement of ICS and KCSV vehicles , as repair costs are expected to significantly increase the unit cost of ICS trams, eliminating the current difference in unit costs between the two types.

The table below (Table 3) summarizes the changes in the daily performance per vehicle type due to such modifications and their impact on the use of costs:

Table 3: Performance changes and their impact on the use of costs

Type	Replaceable km	Replaceable statistical place kilometre	Amount that could be saved (Ft/place kilometre)	Costs that could be saved (thousand Ft)
ICS instead of KCSV7	464	83,559	0.000	-
TK3 instead of T3	702	189,651	0.000	-
TW6 instead of T2	509	91,571	0.000	-
CAF5 instead of Tatra and TW6	405	72,927	0.905	66.0
CAF9 instead of Tatra	198	71,322	0.905	64.5
Combino instead of Tatra	594	213,965	0.905	193.6
In total	**2,873**	**722,993**		**324.1**

Source Own, 2020

The additional place capacity on weekdays due to the above changes would be 71,322 place kilometre (if the CAF9 and Combino trams run on Line 1 instead of the Tatra), the excess service performance due to remise runs and line modifications would be 715 km per day.

On weekdays, the theoretical cost saving effect of vehicle rearrangements is approx. *325,000 HUF/day*, which could result in approx. *80,000,000 HUF/year.*

If I continue the train of thought and examine the possibility of cost saving in case all the vehicles with high place km data in Table 3 (including the ones in the first three lines) could be replaced as an investment for new, low-cost vehicles: in this case, the effects of replacement calculated for one day performance is summarized here below, by Table 4:

Table 4: The effects of replacement for new low-cost vehicles

Type	Replaceable km	Replaceable statistic place km	Theoretically saveable place km cost (HUF/place km)	Theoretically saveable cost (thousand HUF)
CAF5 – replacing KCSV7	464	83 559	3,420	285,8
CAF5 – replacing T3	702	189 651	0,905	171,6
CAF5 – replacing T2	509	91 571	0,905	82,9
CAF5 – replacing Tatra and TW6	405	72 927	0,905	66,0
CAF9 – replacing Tatra	198	71 322	0,905	64,5
Combino – replacing Tatra	594	213 965	0,905	193,6
Total	**2 873**	**722 993**		**864,4**

Source: Own, 2020.

During the examined weekday vehicle availability approximately HUF *865,000* could be saved if all the concerned vehicles were replaced by new ones (this means the replacement of a further stock of 11 vehicles for new ones, from investment).

The new vehicles will extend the number of the possible vehicle replacements on weekends, too. The runs, replaced this way, are summarized by Table 5:

 10.18531/Studia.Mundi.2020.07.03.86-96

Table 5: Possible vehicle replacement on weekends

Tramline	Type	Number of runs to be replaced	Statistical place km to be replaced	Theoretically saved cost for place km (HUF/place km)	Theoretically saveable costs (thousand HUF)
1	T3 replaced by **CAF9**	65	1 545 484	0,905	1 398,7
2	KCSV7 replaced by **CAF5**	364	279 528	3,420	956,0
28-28A	Tatra replaced by **CAF5**	199	344 608	0,905	311,9
37A	Tatra replaced by **CAF5**	154	163 225	0,905	147,7
Total		**782**	**2 332 846**		**2 814,3**

Source: Own, 2020.

During a weekend service appr. HUF *2,814,000*/day can be achieved if all the 11 vehicles are replaced.

Table 6 shows the cost-saving possibilities on annual basis:

Table 6: Cost-saving possibilities

Period:	Number of days	Calculated saving per day (thousand HUF/day)	Total saving (thousand HUF)
Weekdays:	250	864,4	216 100
Weekends and bank holidays	115	1 415,6	323 645
Annual total	**365**		**539 745**

Source: Own, 2020.

On annual level, totally HUF 539,745,000 can be saved by vehicle replacements detailed as above.

It is important to state that this calculation does not consider the present limitations of the infrastructure network, nor any occasionally emerging infrastructure expenses.

In order to facilitate the above described daytime replacements by new vehicles acquisition of 11 units of new vehicles (CAF5 or equivalent) is necessary, as the replacements are partly feasible by the presently available up-to-date low floor vehicles.

Estimated purchase price of the 11 new vehicles: HUF 7,150,000,000.-

The payback time of the investment with simplified calculation:

$$\frac{Acquisition\ value}{Expected\ saving} = Payback\ time\ (year)$$

$$\frac{7\,150.0\ million\ HUF}{539.7\ million\ HUF} = \mathbf{13,2}\ (year)$$

Several influencing factors were not taken into consideration during the calculation of the simplified payback time. Concerning costs, among others, I did not take into account the time values of the cash flows, the incomes from the sale of the scrapped vehicles, the interests on the possible investment loans and the percentage changes in price level. The purpose of defining a theoretical method was to quantify a rough estimation that could be the basis for developing a detailed model for the entire fleet.

Summary

Transportation provides the essential service background of the engine that operates the economy and the society. Its role is to create mobility for individuals, goods and services. Reaching higher standards is ultimately about promoting economic development and balancing territorial disparities. Its development may result in substantial regional development, as its contribution to GDP is also significant. The European Union decision-making bodies have also recognized this correlation between life standard in cities and the development of the transport system, and have therefore encouraged the preparation of sustainable urban mobility plans. Their purpose is to make more efficient and sustainable use of existing transport infrastructures and to render the quality of the provided services attractive, thereby reducing the environmental impact of the transport system and ultimately improving the quality of life in the area concerned.

Today, urban transport is no longer just a service for mobilizing the population, but also a decisive factor in social, economic, political, cultural and ecological terms. It also indirectly contributes to the inhabitability of cities through available, accessible, reliable, affordable, fast and exact, safe, convenient, environmentally and user-friendly transport services.

It can be reasonably concluded that there is a coevolutive link between cities and transportation.

The key driver of the urbanization, evolving due to the geographic concentration and coordination of economic and social activities, is the changes of the transport system. However, physical characteristics of the cities and their changes have a great impact on the development of the transport system. The two terms can also be interpreted both as mutually supportive and inhibiting factors. Public transport development and regional development must always be in accord unless you want to find fault-lines in urban development. Considering these aspects on the long run serves the creation of a better economic, social and spatial structure at the settlement concerned, thereby improving living standards.

Due to their good environmental impacts, favouring urban rail networks is clearly targeted in urban planning today. With regard to the availability and the schedules, concerning the increased and changing performance requirements, companies that operate electric urban railways seek optimization opportunities primarily in order to reduce expenses. The tram transport service provided by BKV Zrt. is performed according to the city’s order, based on quantitative and qualitative parameters. The cost optimization option under this study seeks to reveal potential savings while implementing the daily schedule.

Rearranging the daily availability of the tram vehicles, which operate on different cost levels, and the well-designed investments open the door to reduction of operational costs. The theoretical possibility and its model-like analysis shows that by organisational and investment activities as much as several hundred million HUF can be saved annually.

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