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Assessment of the level of development of the tram network in the capitals of European Union countries

Ocena stopnia rozwoju sieci tramwajowej w stolicach krajów Unii Europejskiej

Abstract. The aim of the paper was to examine the net of the tram transport in the capitals of EU countries. This is a starting point of a larger study that should encompass all European cities. Trams, once considered obsolete, due to their eco-friendly propulsion, external costs associated with the entire life cycle of tram rolling stock, their operational lifespan, their adaptability to modernization, and their low energy consumption, now hold promising prospects. This is also evidenced by the results obtained in this study. It turns out that the capitals of European Union countries, which can be considered a showcase for the state, do not consider tram transport impractical. On the contrary, we are returning to trams usage, which is also caused by increased EU funding. Therefore, some countries already have a well-developed tram network, but others still require significant design work and funding. The study ranks EU capitals in terms of assessing the level of development of tram transport. The authors are aware of the complexity of the problem; the work does not take into account many criteria that should be included in subsequent stages of the research. The most popular classical methods, such as Spearman's rank coefficient, were used, but certain indicators were created by the authors. The calculations are illustrated with graphs that best reflect the actual situation. The main ranking was determined as an average of the positions. This average became a synthetic variable, which is a new idea that fits the goal set in the work.

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Keywords: Spearman's rank correlation coefficient, classification, urban transport, zero-emission transport, tramway

Synopsis. Praca dotyczy transportu tramwajowego w stolicach krajów UE. Stanowi pierwszą część większego badania, które powinno objąć wszystkie miasta europejskie. Tramwaje, jeszcze niedawno uważane za przeżytek, mają obecnie obiecujące perspektywy rozwoju ze względu na ekologiczny napęd oraz niskie koszty zewnętrzne związane z całym cyklem życia taboru, okresem eksploatacji i podatnością na modernizację, a także niskim zużyciem energii. Świadczą o tym również wyniki badania przeprowadzonego w ramach niniejszej pracy. Okazuje się, że w stolicach krajów Unii Europejskiej, które można traktować jako wizytówki tych państw, transport tramwajowy nie jest uznawany za niepraktyczny. Wręcz przeciwnie: obserwuje się wyraźny powrót do korzystania z tramwajów, poparty także finansowaniem unijnym. Niektóre kraje mają już rozwiniętą w dużym stopniu sieć tramwajową, inne potrzebują jeszcze licznych prac projektowych oraz dofinansowania. W artykule sklasyfikowano stolice państw UE pod względem oceny stopnia rozwoju transportu tramwajowego. Autorzy zdają sobie sprawę ze złożoności analizowanego problemu, praca nie uwzględnia wielu kryteriów, które należałoby ująć na kolejnych etapach badań. W niniejszym badaniu zastosowano najpopularniejsze klasyczne metody, np. współczynnik korelacji rang Spearmana, ale niektóre wskaźniki wykreowane zostały przez autorów. Obliczenia zilustrowano wykresami, które najlepiej oddają stan faktyczny. Ranking główny powstał na podstawie średniej z rankingów składowych. Średnia ta stała się zmienną syntetyczną, co stanowi nowy pomysł pozwalający osiągnąć cel założony w pracy.

Słowa kluczowe: współczynnik korelacji rang Spearmana, klasyfikacja, transport miejski, transport zeroemisyjny, tramwaj

JEL codes: L92, C15, C35, C38

Introduction

In this article authors assess the level of development of tram transport in the capitals of European Union countries and compare these cities with each other. The goal was to test how Warsaw, which is noticeably developed in the term of tram network, compares with other countries. The best example of investment in trams in Warsaw was the recent opening (October 2024) of new lines to the Wilanow district along Belwederska, Sobieskiego, and Rzeczpospolitej Streets. This is a massive investment, encompassing not only the tram infrastructure itself, such as new tracks and a modern depot in Annapol, but also the reconstruction of sidewalks and bicycle paths. All investments have been done with the aim of improving public transport and protecting the environment in the same time what is in line with EU strategy. It turns out that, from a utility perspective, despite numerous alternative modes of urban transport, over 10 million passengers have already used the newly created lines, and there is no indication that this trend will change [Tramwaje Warszawskie 2025]. So, what is this phenomenon? Is it unique to Warsaw? At one point, not so long ago, it seemed that the tram would remain a kind of open-air museum, a tourist attraction. Many European cities even

began to phase out tram transport altogether, as happened in Copenhagen, for example. However, it turns out that tram transport is thriving. Many cities maintain it and do not regret this decision [Barmina 2023; Taczanowski et al. 2025]. On the contrary, they continue to develop it, investing in increasingly modern rolling stock, and designing new solutions. It is not without reason that cities that have abandoned this form of transport want to return to it – like mentioned before Copenhagen, but also other European cities [Petkov 2020; Green 2020]. Trams can be easily distinguished technically from other means of rail transport, but in the case of a so-called rapid tram, it serves as a pre-metro. The main condition is that it does not interfere with roads, which usually means that part of the line runs in a cut, on a viaduct/embankment, or in a tunnel. Due to the design of tram rolling stock, which does not meet the requirements for rail vehicles, it cannot function as a train. However, there are cases where trams share railway lines – this applies to individual lines or sidings of local importance, where rail traffic is low [Naegeli et al. 2012; Arvidsson & Browne 2013; Metelka & Janoš 2024]. This study, however, does not address the topic such as multitude of applications for this type of vehicle. It focuses more on the essence of the level of development of tram networks within cities regardless of how this type of passenger transport is used. The selection of EU capitals for this study is rather pilot study; the starting point of the research that is planned to be conducted on a much broader scale than presented in this manuscript. Therefore, the EU capitals should be treated in this case as a kind of representative sample of EU countries, although the authors realize that, on a global scale, the results will differ from those obtained in this study which is focused on capitals only. At the same time, from the point of view of tourism, the capital of a country is often its showcase, the city with the largest population and the most urbanized area, so it is worth comparing the public transport network between capitals.

Materials and methods

Since the study aims to compare the level of development of tram transport networks in EU capitals, cities where this mode of transport does not currently exist were excluded from the study from the outset. These included Copenhagen (Denmark), as well as Ljubljana (Slovenia), Nicosia (Cyprus), Valletta (Malta), and Vilnius (Lithuania). The following variables were selected for the study:

LTN – Length of the city's tram network in km

NLT – Number of tram lines in the city

ART – Area of the city in km²

POP – Number of inhabitants in thousands.

Data on these variables are presented in Table 1.

To improve the readability of the graphs, the names of the capitals were replaced with three-letter abbreviations. In most cases, these abbreviations correspond to the IATA code, because they are usually clearly recognized as the city name. Unfortunately, sometimes a given city has more than one significant airport or uses an airport in another city. In such cases, the three-letter code was assigned arbitrarily. This applies to Paris (PAR*) and Rome (ROM*). Additionally, in the case of the Netherlands, Amsterdam* was assumed

Table 1. Empirical data

Tabela 1. Dane empiryczne

Country	Capital city	Code	LTN	NTL	ART	POP
Austria	Vienna	VIE	167	27	415	1897.5
Belgium	Brussels	BRU	128	18	161	1200
Bulgaria	Sofia	SOF	74.3	15	492	1480
Croatia	Zagreb	ZAG	58	15	641	699
Czech Rep.	Prague	PRG	146.3	31	496	1324
Estonia	Tallinn	TLL	17.2	4	159	440
Finland	Helsinki	HEL	46	9	213	660
France	Paris	PAR*	184.4	15	105	2148
Germany	Berlin	BER	194	22	892	3900
Greece	Athens	ATH	27	2	39	665
Hungary	Budapest	BUD	155	26	525	1750
Ireland	Dublin	DUB	44.5	2	118	554
Italy	Rome	ROM*	40	6	1287	2860
Latvia	Riga	RIX	54.7	7	307	700
Luxemburg	Luxemburg	LUX	16,1	1	51	122
Poland	Warsaw	WAW	134	25	517	1862
Portugal	Lisbon	LIS	48	5	100	505.5
Romania	Bucharest	BBU	141	22	240	1800
Slovakia	Bratislava	BTS	42	5	368	437.7
Spain	Madrid	MAD	27.sie	3	604	3266
Sweden	Stockholm	STH	38.8	5	187	980
The Netherlands	Amsterdam*	AMS	200	16	219	872

Source: own elaboration based on [Phipps, Schwandl 2023; UrbanRail.Net 2025]

Źródło: opracowanie własne na podstawie [Phipps, Schwandl 2023; UrbanRail.Net 2025]

to be the capital. It is the constitutional capital of the Netherlands, the administrative capital is The Hague, which was not included in the study. Ultimately, the study was limited to 22 capital cities.

In this study, it was decided to create dedicated rankings, where so-called ranks will be used to determine the position of each capital city among the others. After sorting the values by a selected characteristic, in an order determined by the researcher, for identical characteristic values, the ranking position is the average of the positions occupied. This means that the positions occupied in the ranking may also have non-integer values. The validity of a rank-based study stems from the appropriate treatment of outliers, which can artificially inflate or underestimate the relationships between traits. Keeping this in mind, the authors of the study created appropriate figures and determined Spearman's rank

coefficients between individual characteristics. The Spearman's rank correlation coefficient (r_s) was calculated based on the commonly used Pearson linear correlation coefficient expressed by formula (1) [Aczel, Sounderpandian 2018, p. 929–934; Stanis 2006, p. 289–318]:

$$r_s = \frac{\sum_{i=1}^n (RX_i - \overline{RX}) \cdot \sum_{i=1}^n (RY_i - \overline{RY})}{\sqrt{\sum_{i=1}^n (RX_i - \overline{RX})^2} \cdot \sqrt{\sum_{i=1}^n (RY_i - \overline{RY})^2}} \quad (1)$$

Where:

$i = 1, \dots, n$ is the observation number for $i \in \mathbb{N}^+$ (\mathbb{N}^+ is a set of positive natural numbers)

RX_i – ranks assigned to individual observation values for feature X

RY_i – ranks assigned to individual observation values for feature Y

\overline{RX} , \overline{RY} – arithmetic means of the observation values for feature X and feature Y , respectively.

Due to the significant differences in the area of the studied capitals and the number of inhabitants, the reliability of assessing the level of development of tram networks based solely on the LTN and NTL variables could be questionable. Therefore, to ensure greater comparability, the authors of this study decided to introduce five indicators that could allow the creation of a final ranking. Therefore, the following variables were introduced (2):

$$X_1 = \frac{LTN}{NTL}, X_2 = \frac{LTN}{ART}, X_3 = \frac{NTL}{ART}, X_4 = \frac{LTN}{POP}, X_5 = \frac{NTL}{POP} \quad (2)$$

In this case, variable X_1 represents the number of kilometers of tram network per tram line in each city. The values obtained using this indicator should be arranged in ascending order, meaning lower indicator values indicate a higher rank in the ranking. This is justified – the resulting ranking will not artificially underestimate or overestimate the positions occupied by individual cities and will, in a sense, take into account the way in which individual tram networks connect the city. Figure 1 illustrates the rationale behind this approach.

The horizontal axis shows the ranking positions of individual capital cities in terms of network length (LTN), while the vertical axis shows their ranking positions in terms of the number of lines (NTL). It can be seen that the ranking positions of individual capital cities vary depending on the approach. In some cases, the differences are quite significant – especially since we're talking about only 22 locations. In the case of Amsterdam (AMS) and Paris (PAR*), there are as many as 7 positions, Dublin (DUB) 5.5 positions, and Prague (PRG) 5 positions. In the case of Warsaw (WAW), there are 4 positions. If the rankings were identical, the points would lie on the diagonal of the square.

The authors therefore consider it appropriate to relate these two values in the form of a quotient. This would make the ranking based on such an indicator

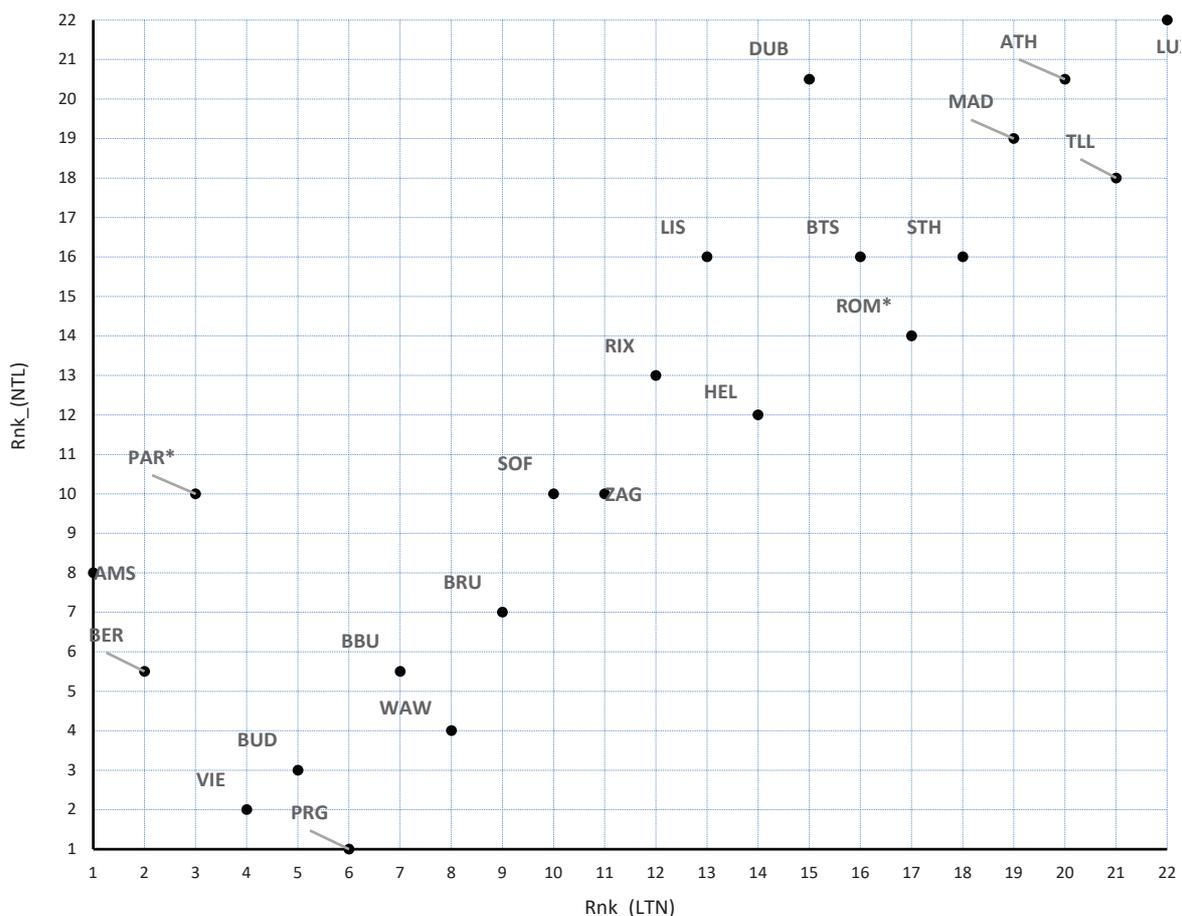


Figure 1. Comparison of rankings for LTN and NTL

Rysunek 1. Porównanie miejsc w rankingach pod względem LTN i NTL

Source: own elaboration

Źródło: opracowanie własne

more coherent and perhaps more transparent, as shown in Figure 2. In this figure, the order in which the bars are arranged corresponds to the order in which they are arranged relative to the X_1 variable. Above the bars, the decision was made to place values representing the bar heights, which are also the values assumed by the X_1 variable for each capital city. Additionally, the studied objects were divided into classes relative to this variable. Because the data are characterized by a relatively large range, they decided not to establish equal-span classes, choosing instead to define their widths rather arbitrarily, leaving the extreme boundaries open. In the case of variable X_1 (in ascending order), capitals with the index value less than 8 were assigned to class 1 (cl_1), and those with values 8 and higher were assigned to class 2 (cl_2), but less than 13, and to class 3 (cl_3) with values of 13 or greater. The division into classes was not accidental; the authors arbitrarily selected this division from several sample classes to avoid classes containing a single element, and to ensure readability of the visualization. They attempted to collect very diverse data and present it simply in the form of a graph.

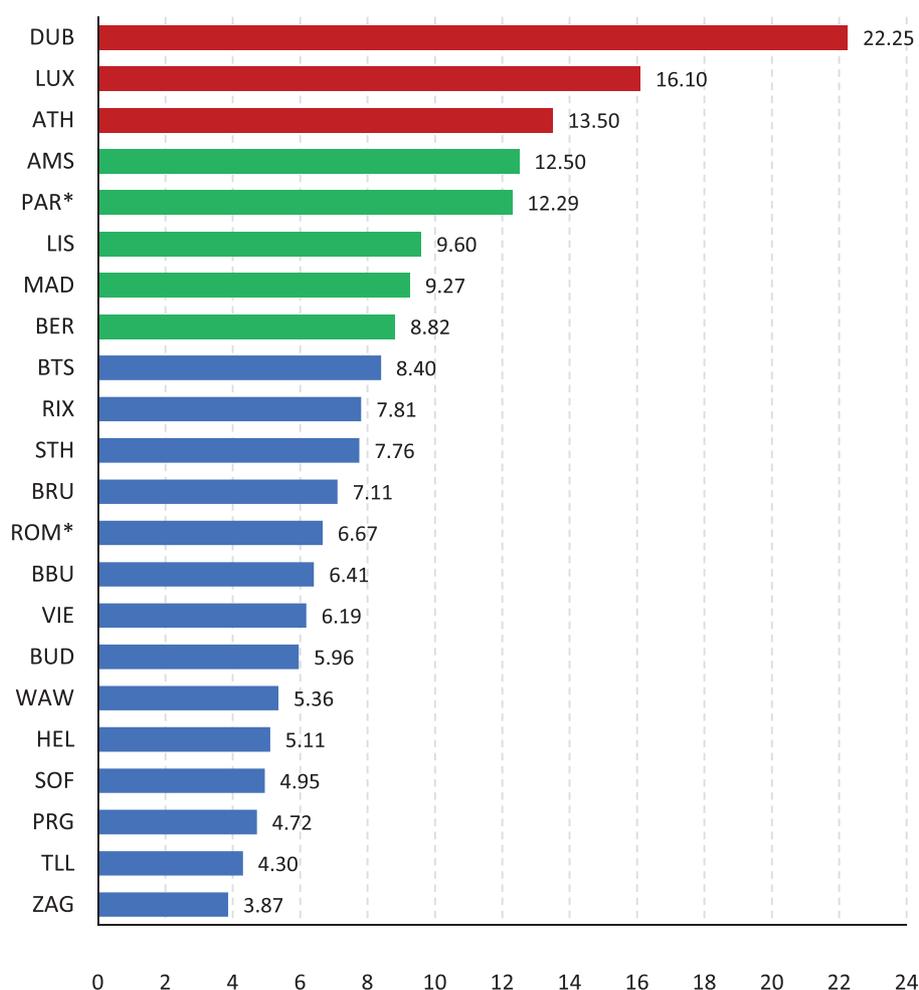


Figure 2. Ordering capitals with respect to variable X_1 – example

Rysunek 2. Uporządkowanie stolic względem zmiennej X_1 – przykład

Source: own elaboration

Źródło: opracowanie własne

From the arrangement of points in both comparisons, it's clear that this change in approach completely altered the previously constructed rankings, based solely on LNT and LTN. The differences in rankings are sometimes very large for some cities compared to the ranking based on the X_1 index, which combines LNT and LTN simultaneously.

Variable X_2 denotes the length of the tram network per 1 km² of the city's area.

According to the authors, the city's area is also an important element in the study, which assesses the quality of the network. The ranking based on this variable will be arranged in descending order.

Variable X_3 , by analogy, is the number of lines per 1 km² of the city's area. The ordering is also descending.

Variable X_4 denotes the length of the network per 1,000 inhabitants. The ordering is descending.

Variable X_5 is the number of lines per 1,000 inhabitants. The ordering is descending.

In the final stage of the study, a final ranking was constructed based on the average of the places each capital city achieved in five rankings on variables X_1 to X_5 [Bałchanowski & Boryczka 2023; Mathieu & Mauras 2018].

Results and discussion

In accordance with the previously presented intentions, a study was conducted, the results are presented in Table 2 with the explanation. Date shows the positions occupied by the capital cities in the rankings based on variables X_1 to X_5 . The “Average” column indicates the average position of each capital city in each of the rankings. The “Rnk_G” column determines the ranks for this average according to the rules described in the Materials and Methods section. The capital cities were arranged in non-decreasing

Table 2. Final results of the rankings created for variables X_1 to X_5 along with the global ranking Rnk_G

Tabela 2. Wyniki końcowe rankingów dla zmiennych od X_1 do X_5 wraz z rankingiem końcowym Rnk_G

Capital	Rnk_(X ₁)	Rnk_(X ₂)	Rnk_(X ₃)	Rnk_(X ₄)	Rnk_(X ₅)	Average	Rnk_G	Class
PRG	3	11	6	3	1	4.8	1.5	cl_1
BRU	11	3	2	4	4	4.8	1.5	cl_1
AMS	19	2	4	1	3	5.8	3	cl_1
VIE	8	7	5	8	6	6.8	4	cl_1
BUD	7	10	9	7	5	7.6	5.5	cl_2
BBU	9	5	3	12	9	7.6	5.5	cl_2
PAR*	18	1	1	9	16	9	7	cl_2
ZAG	1	20	16	10	2	9.8	8	cl_2
WAW	6	12	10	14	8	10	9.5	cl_2
LIS	17	6	8	6	13	10	9.5	cl_2
HEL	5	14	11	15	7	10.4	11	cl_2
SOF	4	17	12	16	11	12	12	cl_2
LUX	21	9	18	2	15	13	13	cl_3
BTS	14	18	20	5	10	13.4	14	cl_3
TLL	2	19	14	20	14	13.8	15.5	cl_3
ATH	20	4	7	18	20	13.8	15.5	cl_3
RIX	13	16	17	13	12	14.2	17	cl_3
STH	12	15	13	19	18	15.4	18.5	cl_3
BER	15	13	15	17	17	15.4	18.5	cl_3
DUB	22	8	19	11	19	15.8	20	cl_3
ROM*	10	22	22	21	21	19.2	21	cl_3
MAD	16	21	21	22	22	20.4	22	cl_3

Source: own calculations

Źródło: obliczenia własne

order according to these ranks. Additionally, the colors of the fields in the table indicate the class assigned to them depending on the ranking:

White – class 1 – high level of tram transport development for the indicator

Gray – class 2 – medium level of tram transport development for the indicator

Black – class 3 – low level of tram transport development for the indicator.

For variables X_1 to X_5 , classes were assigned based on the values obtained for individual objects on the coefficients. Therefore, classes were assigned to objects for specific indicator values, as shown in Table 3:

Table 3. Rules for assigning ranking classes to the values of variables from X_1 to X_5

Tabela 3. Zasady nadawania klas rankingów dla wartości zmiennych od X_1 do X_5 .

Ranking	Class_1	Class_2	Class_3
Rnk_ X_1	(~ – 8)	[8 – 13)	[13 – ~)
Rnk_ X_2	[0.6 – ~)	[0.3 – 0.6)	(~ – 0.3)
Rnk_ X_3	[0.06 – ~)	[0.03 – 0.06)	(~ – 0.03)
Rnk_ X_4	[0.1 – ~)	[0.05 – 0.1)	(~ – 0.05)
Rnk_ X_5	[0.01 – ~)	[0.005 – 0.01)	(~ – 0.005)

Source: own elaboration

Źródło: opracowanie własne

A similar approach was taken when dividing the main ranking into classes (Rnk_G). Here, by analogy, the division criterion was the “Average” column, where:

Class_1: Average \in [1 – 7)

Class_2: Average \in [7 – 13)

Class_3: Average \in [13 – ~).

The main “Rnk_G” ranking was tied between Prague (PRG) and Brussels (BRU). These capitals jointly ranked 1.5, as the average of 1 and 2. The fluctuations in these cities’ positions in the individual rankings can be seen in Figure 3.

Warsaw (WAW) seems to be an interesting case in our calculations. Ultimately, it placed in the middle of the rankings, at 9.5, but it shares this position with Lisbon (LIS). The case of Warsaw (WAW) is interesting because it maintains a relatively stable position among other capital cities regardless of the criterion (similar to Vienna – VIE). Figure 4 shows the positions occupied by Warsaw (WAW) and Lisbon (LIS) in the respective rankings.

In the overall ranking, it’s worth paying particular attention to the composition of Class 1 and Class 3. The high ranks of Prague (PRG), Brussels (BRU), Amsterdam (AMS), and Vienna (VIE) demonstrate that it’s inaccurate to describe trams as relics of the past. They continue to play an important role in public transport and bring many benefits, both to tourism (sometimes a tourist attraction, as in Lisbon), and to environmental protection. In some capital cities, trams are the primary means of transport (e.g. Vienna, Amsterdam), serving major arteries, while in others they complement the rapid underground railway (e.g. London, Paris). The tram clearly supports current Euro-

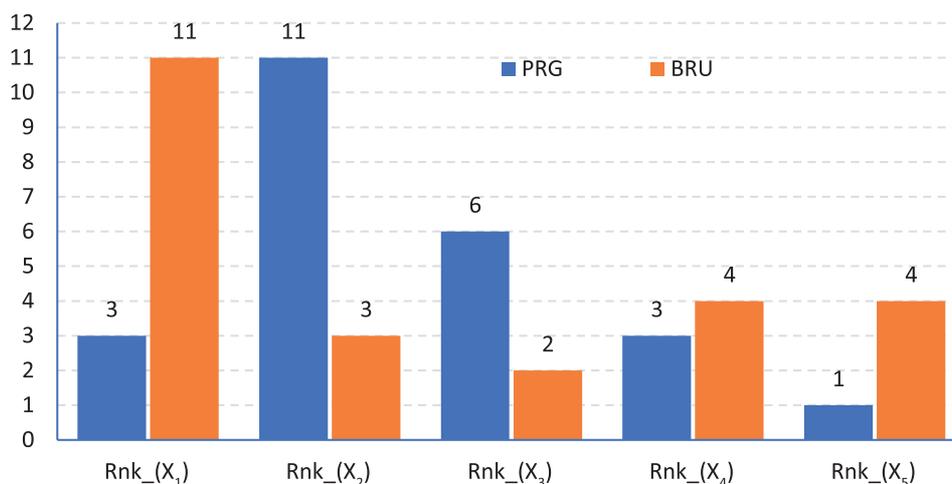


Figure 3. Rankings for Prague (PRG) and Brussels (BRU)
 Rysunek 3. Miejsca rankingowe Pragi (PRG) i Brukseli (BRU)

Source: own elaboration

Źródło: opracowanie własne

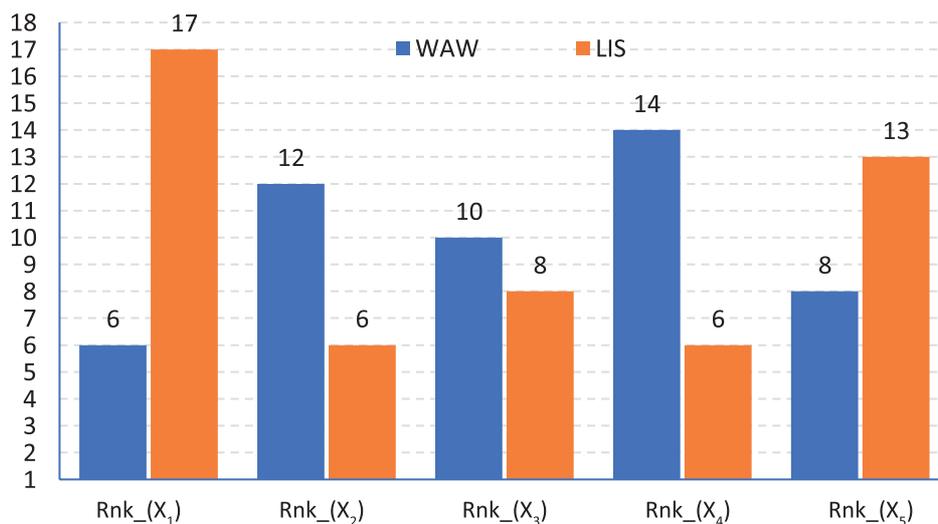


Figure 4. Rankings for Warsaw (WAW) and Lisbon (LIS)
 Rysunek 4. Miejsca rankingowe Warszawy (WAW) i Lizbony (LIS)

Source: own elaboration

Źródło: opracowanie własne

pean environmental policies. Regarding Class 3, which includes capital cities such as Stockholm (STH), Berlin (BER), Rome (ROM), and Madrid (MAD), simple answer to the question “what does the low places in the ranking for those cities mean?” is not obvious and needs to be better examined and explained in the future studies. Probably these cities still rely on less ecological means of urban and individual transport such as cars, scooters and buses, but they also use the high-speed rail network, such as Berlin. The final ranking in this study didn’t take everything into account, many other fac-

tors were omitted, and some could be connected with this research results like terrain or network coverage of other types of transport. Much depends on the quality of the tram fleet, alternative modes of urban transport, and the methods of classifying them. Perhaps some of the variables should have been weighted? This study treated all criteria equally. There are also certain architectural, spatial planning, urban planning, and other constraints that sometimes prevent the expansion of tram networks. However, it should be noted, that many cities have excellent public transportation without trams, yet they still plan to further develop tram networks rather than eliminate them from everyday life.

Finally, we also present the Spearman's rank correlation coefficient matrix, as defined in formula (1), which will demonstrate the relationships between the component rankings and the overall ranking. This matrix is presented in Table 4.

Table 4. Spearman's rank correlation matrix between component rankings and the main ranking

Tabela 4. Macierz korelacji rang Spearmana pomiędzy rankingami składowymi a rankingiem głównym

Ranking	Rnk_X₁	Rnk_X₂	Rnk_X₃	Rnk_X₄	Rnk_X₅	Rnk_G
Rnk_X ₁	1					
Rnk_X ₂	-0.4636	1				
Rnk_X ₃	0.0807	0.8046	1			
Rnk_X ₄	-0.1711	0.5697	0.4195	1		
Rnk_X ₅	0.5494	0.2163	0.5008	0.6544	1	
Rnk_G	0.3127	0.5920	0.8165	0.7323	0.86288	1

Source: own calculations

Źródło: obliczenia własne

It can be seen that some of the rankings differed significantly, while others were more similar. It should be remembered, however, that this work does not concern the assessment of the convergence of the rankings, but rather the construction of a main ranking that takes into account as many criteria and the information contained within them as possible. As an example, we decided to use the Rnk_X₅ ranking, which is closest to the main ranking (Rnk_G). In this case, the Spearman's rank correlation coefficient was 0.86. While this is a relatively high correlation, it is also important to remember that our ranking covers only 22 objects, so the position a given object occupies within it is not insignificant. The discrepancies in these positions are shown in Figure 5. The differences in some cases are very visible. The most prominent examples include: Paris (PAR*, 9 positions), Zagreb (ZAG, 6 positions), Riga (RIX, 5 positions), Athens (ATH, 4.5 positions), Helsinki (HEL, 4 positions), Bratislava (BTS, 4 positions), Bucharest (BBU, 3.5 positions) and Lisbon (LIS, 3.5 positions).

Amsterdam (AMS), Rome (ROM*), and Madrid (MAD) occupy essentially the same position in both rankings. Therefore, it seems that the concept of assessing the quality and development of the tram network using a multi-criteria approach should not be controversial, although the authors agree that a different approach and a larger number of criteria would likely have resulted in different results, however, it is typical for rankings creation.

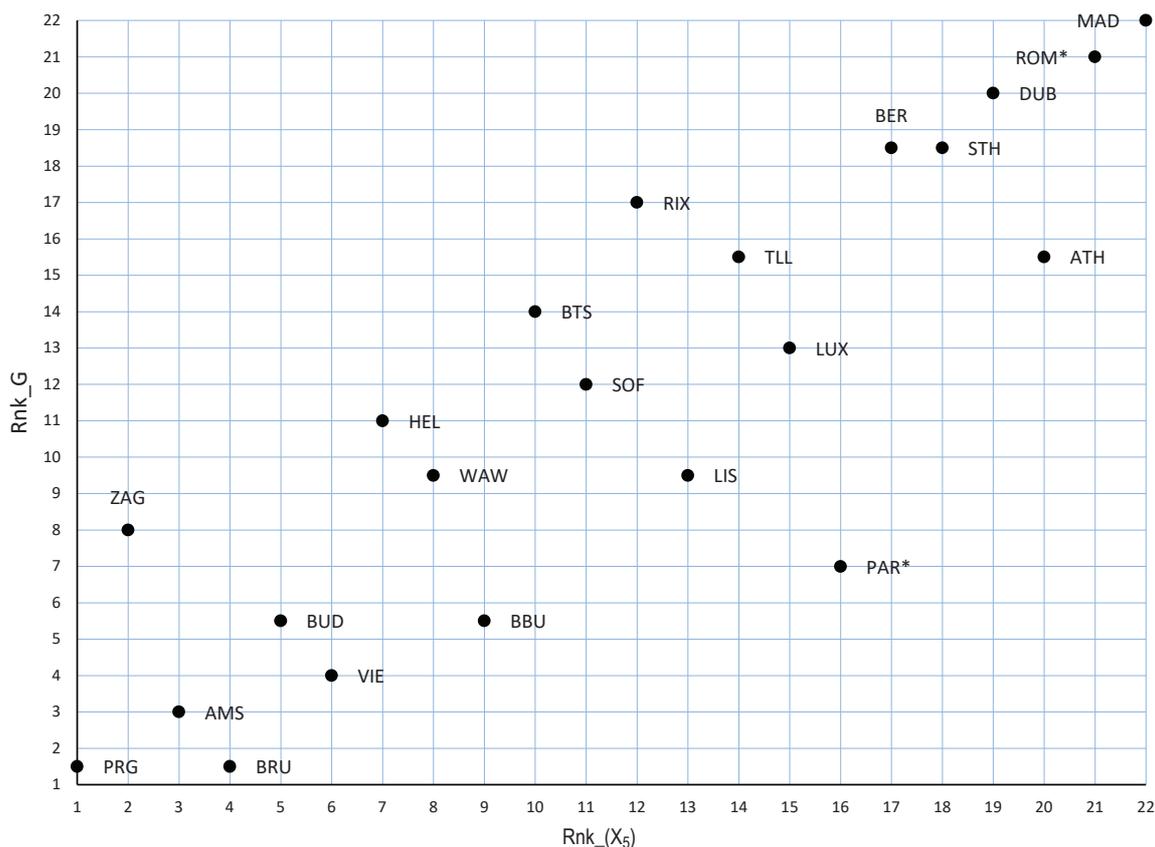


Figure 5. Comparison of Rnk_X₅ and Rnk_G rankings
 Rysunek 5. Porównanie miejsc rankingowych Rnk_X₅ i Rnk_G

Source: own elaboration

Źródło: opracowanie własne

Summary and conclusions

The authors of the study believe that trams are an important topic, or at least one that deserves attention. Tram transport offers many benefits – being powered by electricity, which means they don't generate as much pollution in the city as vehicles powered by combustion engines. Even electric cars and buses are to some extent more harmful to the environment, if only because heavy metals must be extracted to produce batteries, which necessitate their disposal at the end of their service life. Trams don't face this problem. It's known fact that trams also contribute to environmental pollution through their electricity consumption, but the continued emphasis on renewable energy sources will mitigate this problem [Choi et al. 2022; Leopa & Anghelache 2015].

It is worth noting that rolling stock, including trams, is more amenable to modernization, meaning that after 30 years it can be rebuilt and still be used. In the case of buses, this time is much shorter. It's obvious that trams, especially modern ones, are expensive, but the costs are offset by their service life. Trams also have greater passenger capacity than buses [Zespół Doradców Gospodarczych TOR 2019].

Another important argument in favor of trams is traffic regulations [Duan et al. 2024, Czerepicki et al. 2021]. In most cases, they have priority over other road users. This is crucial during rush hours. It seems that this study is only the starting point to wider research. The topic is broad and this study can be treated as the pilot or an introduction to this topic. The criteria themselves may raise some concerns as they may be too narrow to draw the final conclusions. The authors realize that limiting the study to the capitals of EU countries does not provide a picture of the entire coverage of the connection network in each country, as there are also not capital cities with a strong importance for tram lines. There are many cities in Europe and around the world with much more developed tram infrastructure, rolling stock quality, and coverage, so this data is incomparable on the country level. At the same time with the large amount of data collected from various cities in studied countries, another and more complicated research method should be used. This work is an attempt to address the topic, but still, there is much to ponder. Capital cities should work on a larger network of eco-friendly rail vehicles. In Warsaw, for example, old routes are being reinstated.

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