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METRO AS AN EXAMPLE OF AN URBAN RAIL SYSTEM. FOUR CASE STUDIES FROM EUROPE

Summary. Underground, tube, subway or metro are common expressions used to describe a rapid transit system serving urban areas. Such a system uses dedicated rail corridors, can run underground or overground, and often includes tunnels and viaducts. Although there are 148 cities in the world with metro systems, each system is different, in terms of layout, length, capacity, etc., as it serves different geographical and socio-economical areas. In this context, the paper presents four European metro systems (Sofia, Warsaw, Lisbon, and Tyne and Wear), introduces the systems dimensions, rolling stock and ticketing strategies and compares similarities and differences between the systems. The analyses suggest a number of recommendations and improvements, which if implemented, could benefit other metro systems in Europe and beyond.

METRO JAKO PRZYKŁAD ZURBANIZOWANEGO SYSTEMU KOLEJOWEGO. CZTERY PRZYKŁADY Z EUROPY

Streszczenie. W języku angielskim występuje wiele określeń opisujących metro. System ten wykorzystuje dedykowane korytarze kolejowe, mogące pracować pod ziemią lub nad ziemią i często obejmuje tunele oraz wiadukty. Mimo że istnieje na świecie 148 miast mających systemy metra, każdy system jest inny pod względem układu, długości, pojemności itp., ponieważ występują w różnych układach geograficznych i systemach społeczno-ekonomicznych. W tym kontekście, artykuł prezentuje cztery europejskie systemy metra (Sofii, Warszawy, Lizbony i Tyne and Wear), przedstawia wymiary systemów metra, taboru, strategię biletową i porównuje podobieństwa i różnice pomiędzy nimi. Analizy wskazują wiele zaleceń i usprawnień, które jeżeli zostaną wdrożone, mogą przynieść zysk dla systemów metra w Europie i poza nią.

1. INTRODUCTION

A metro is an urban transport system, which uses exclusive rails to run uninterrupted high capacity trains. The metro trains are composed of minimum two cars and have a capacity of carrying a minimum of 100 passengers. Metro systems often involve some level of automation, from for example automated on-train announcements (Tyne and Wear Metro) to fully automated and driverless trains (e.g. Dubai Metro). Other types of rail systems, such as light rail, magnetic levitation or monorail technology are usually included in metro systems statistics. There are 148 cities with metro systems around the world and most of them are located in Europe and Asia [15]. The busiest metro system in Asia, which carries over 3.2bn passenger trips per year, is Tokyo Metro, whereas Moscow's metro is the busiest metro system outside Asia with 2.4bn passenger trips per year [15]. Although the first metro system was opened in London in 1863 [14] there are ongoing construction works around the world today with new lines opening in 2013 in Brescia (Italy) or Harbin and Zhengzhou (China) [15]. Overall, the length of the world's metro lines is 11,000 kilometres serving 9,000 metro stations with an average distance of 1.2 kilometres between the stations [9], [12].

The paper presents European metro systems located in the capital cities of Bulgaria (Sofia), Poland (Warsaw), and Portugal (Lisbon) and a county located in the North East of England (Tyne and Wear). The aim is to introduce the systems dimensions, rolling stock and ticketing strategies and compare similarities and differences between the systems in order to exchange good practices and suggest improvements to the existing and new metro systems in Europe and beyond.

This paper is structured as follows. Firstly, the four metro systems are introduced and described individually, taking into account a number of set criteria. Secondly, the data for the four systems and their technical specifications are analysed, compared and commented. Finally, main conclusions and recommendations for the future work are presented in the last section.

2. EUROPEAN METRO SYSTEMS

There are 45 metro systems in Europe with Moscow and Paris being amongst the ten busiest metro networks in the world [15]. London Underground, known as Tube, is the oldest metro system in Europe and the world. Moreover, it is also the world's fourth longest subway system with 402 kilometres of route length in total (Railway Technology, 2014). 86% of European metro lines can be found in the EU-15 country group and only five metro systems are located in New Member States [16].

A comparison of the four metro systems, two from EU-15 country group and two from NMS is presented. Each of the four metro systems is based in a different country, has its own history and socio-technical characteristics and faces its own opportunities and challenges in the future.

2.1. Sofia Metro

Sofia Metro, owned by Sofia Municipality, is the only metro system in Bulgaria. It links highly populated districts and aims to provide passengers with safe and fast transport services. Currently, after the completion of lines 1 and 2, Sofia Metro has reached 450,000 users per day [10]. In fact, its share in terms of public transport is quite high, with 38% of the total number of journeys in the Bulgarian capital city made by metro.

The construction of the Sofia Metro began in 1978, however the first six stations were open twenty years later, in 1998. Since then there has been a phased opening, mainly in 2009 and 2012. In 2014 there are two lines built and in use with a total length of 31 kilometres and 27 stations (Fig. 1)[4]. According to the General Master Plan [4] report there are 36 more metro stations planned to be built in the future. The existing sections of the metro system are underground with only three stations outside on trestles. The whole metro network planned for Sofia includes three lines with total length of 65 kilometres, 63 stations and capacity for 1,2 million passengers per day [3], [4]. Metropolitan EAD, owned by Sofia Municipality, runs both construction and operation of the Sofia Metro.

Sofia Metro uses 52 metro trains produced by Russian locomotive manufacturer, Metrovagonmash. The vehicles are of two types: older 81-717/714 and new 81-740/741, designed for use in tunnels and in open areas and to run in winter conditions [13].

In terms of ticketing, there are several types of fares offered to Sofia Metro users, from a single ticket (1,00 lev = £ 0,41), ticket bundles (10 single trips loaded in electronic card cost 8,00 lev (£ 3,27) plus 1,00 lev for 3-year valid card), a day ticket (4,00 lev = £ 1,63) to a monthly ticket (price varies from 35,00 lev = £ 14,29 to 42,00 lev = £ 17,14) [13].

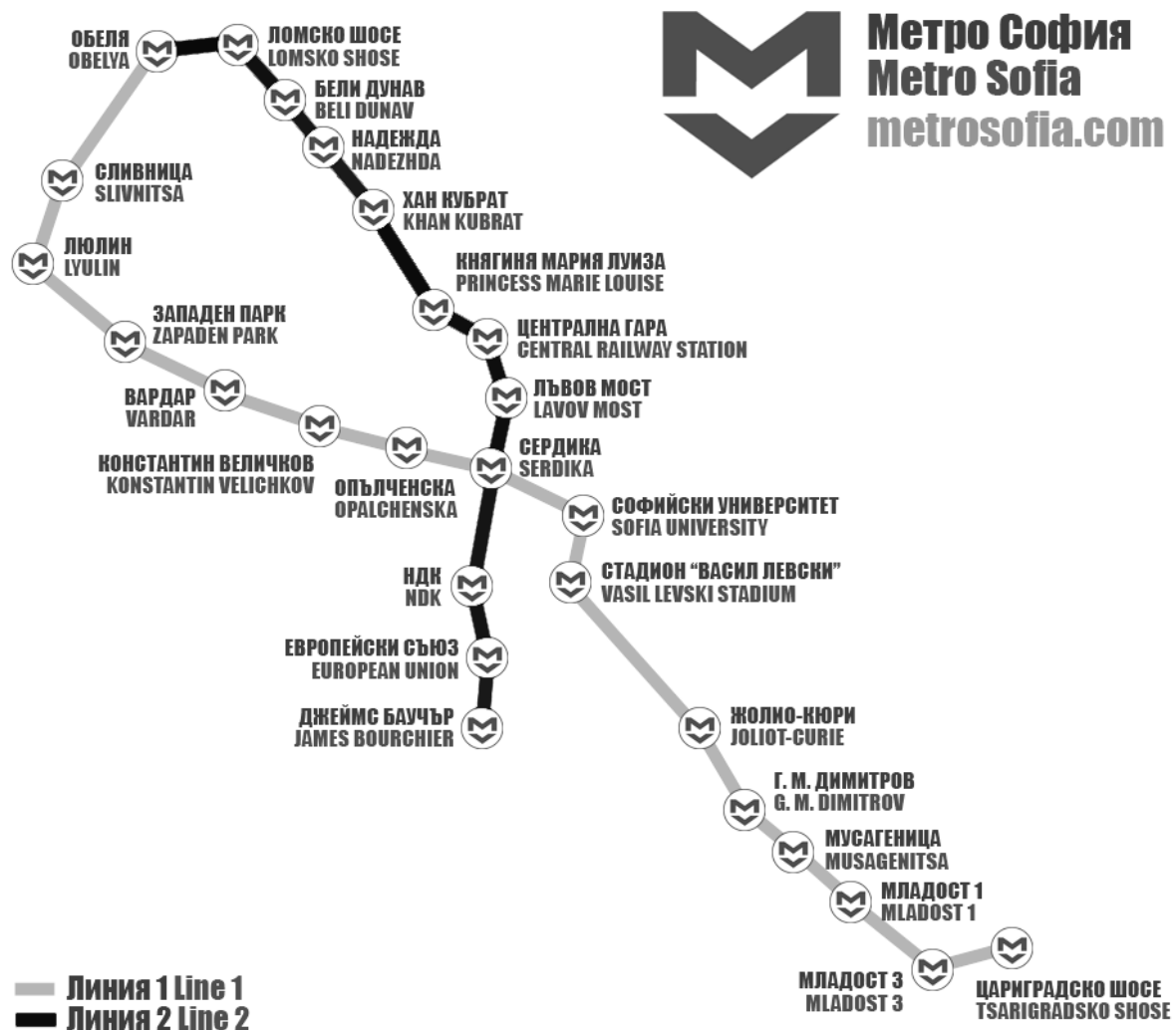


Fig. 1. Current Compact Sofia Metro Plan

Rys. 1. Obecny i uproszczony plan metra w Sofii

2.2. Warsaw Metro

Warsaw Metro is only one metro system in Poland. Its origins date back to 1995 and the need for the system was foreseen with the increasing number of residents in the capital city of Poland. By 2014 only one line has been built and put into service, although the metro's expansion is foreseen, as presented on (Fig. 2) [5]. The system consists of 21 stations and 22.7 kilometres of railways. The expansion of the system is progressing gradually and in 2014 there are seven new metro stations under construction in Warsaw.



Fig. 2. Current metro line (dark line) and scheduled (lighter lines)
 Rys. 2. Obecna linia metra (czarna linia) i projektowana (jaśniejsza)

The existing metro network and stations in Warsaw are all located underground and the stations have large dimensions. The fact is that there is no urban space available at the surface to build a network with different features. Although Warsaw Metro is not as commonly used as desired, the reason for this is that other urban modes are better developed in the city and the city coverage of the metro system is still very limited and lacks of capacity. Although Warsaw Metro carries 568,000 passengers per day, the most efficient and modern public transport mode in Warsaw is actually a light rail system, called SKM. In terms of frequency, trains are running every 15 minutes, almost constantly during all day.

There are three types of metro trains used in Warsaw Metro system and these include various models of 81 Series by Metrovagonmash; Metropolis trains produced by Alstom and newly ordered

Inspiro trains manufactured by Siemens. The metro uses 240 coaches configured in 40 six-coach trains [5].

There is only one public transport operator in Warsaw, called ZTM, who operates Warsaw Metro, SKM as well as buses, and who is also responsible for ticketing. One ticket is valid in all modes of transport, which means that multimodal tickets are fully implemented in Warsaw. With regards to the prices, a single ride costs 7 PLN (£ 1,32) and a daily ticket costs 26 PLN (£ 4,90) [5].

2.3. Lisbon Metro

Lisbon Metro entered in service in 1959 and is the only metro system in Portugal. Lisbon underground became an important element towards the development of the city as well as its expansion due to its safety, speed and reliability. Originally, the first section of the metro line had a Y-shape. Since then, there were several steps in terms of its construction and expansion, mainly in 1963, 1988, 1998, and 2009 [6]. Nowadays Lisbon metro has 49 stations and network's total length is 45 kilometres.

Lisbon Metro uses four types of trains (ML90, ML95, ML97 and ML99), all produced by Siemens. There are 113 3-coach train sets in use serving the four lines of the metro system.

In terms of intermodal ticketing, some important steps have been taken in the direction of implementing this approach and currently several options regarding integration of different modes are available in the whole metropolitan area of Lisbon. A one single metro ticket costs € 1,25 (£ 1,00) and a one day ticket costs € 6,00 (£ 4,80) and it is valid also for city buses.

2.4. Tyne and Wear Metro

Tyne and Wear is a county located in North East England near the mouths of the rivers Tyne and Wear. Tyne and Wear Metro is one of three metro systems in the UK, although it is not a typical metro system as there is a number of level crossings and some sections of the rails are shared with rail regional services. The metro concept for Tyne and Wear was conceived in 1971 and the system started its operation in 1980.

The system consists of 77,5 kilometres of track and 60 stations [1],[2], [8]. It provides integrated public transport with bus and other rail services [8], as many of the stations are interchanges. A number of extensions to the existing network of stations were introduced in 1991 and 2002 (Fig. 4) and further extensions to the metro system are under consideration [1].

Tyne and Wear Metro uses a total of 90 two-coach trains, which are in operation since 1980. These trains were built around 1980 by a UK-based manufacturer, Metro Cammell. A number of upgrades was introduced to the rolling stock, including interiors and exteriors. The metro plans to purchase a new fleet of trains after 2025.

Regarding public transport fares, under the Nexus umbrella there are a huge amount of different types of tickets, either in terms of area covered, temporal scope (one week, one month or one year, for example) or modes integrated (unimodal or multimodal). One example of fares is a single journey by metro, that costs £ 1,80, £ 2,60 or £ 3,30, depending on the number of zones crossed. In terms of day tickets, it costs from £ 2,60 until £ 4,50.

3. COMPARISON OF THE FOUR METRO SYSTEMS

The four European metro systems presented in the previous section show a variety of concepts, from length of lines to ticketing strategies. Table 1 shows a concise comparison of technical specifications of the four systems.

Tyne and Wear Metro has the largest dimension and territorial scope of the metro systems considered. The fact is that Tyne and Wear metro is three times longer than Warsaw's metro and almost doubles Lisbon's in terms of track length. However, due to its regional scope, instead of urban, it has the smallest number of stations per kilometre.



Fig. 3. Lisbon Metro network diagram
Rys. 3. Plan metra w Lizbonie

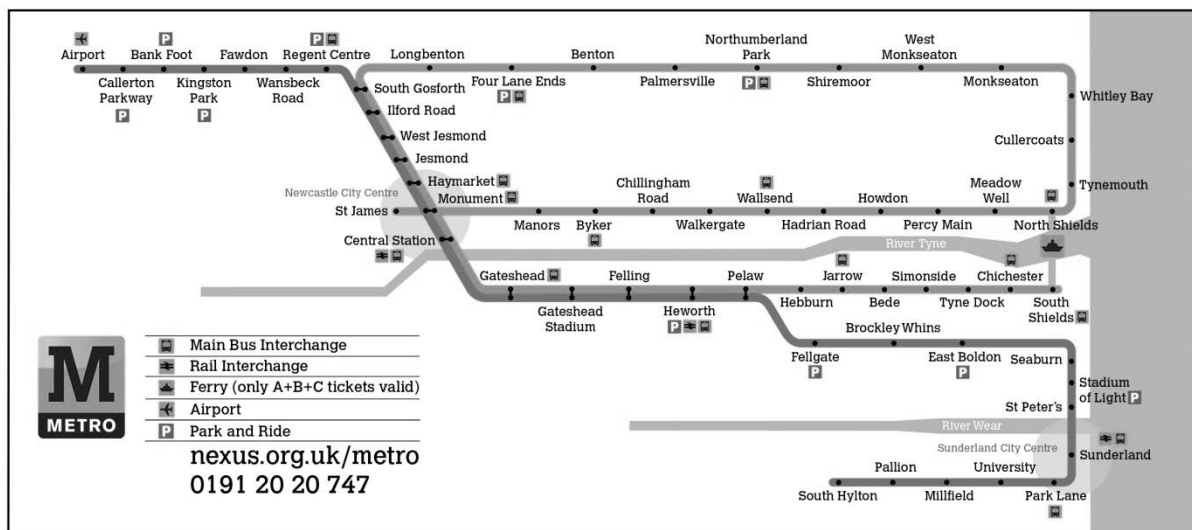


Fig. 4. Tyne and Wear Metro map
 Rys. 4. Mapa metra Tyne and Wear

Table 1

Characteristics of the four metro systems

Name	Open [year]	Latest extension [year]	System length [km]	Number of stations	Number of lines	Rolling stock (name/manufacturer)	Number of vehicles	Daily ridership	Tickets		
									Single fare [£]	One-day fare [£]	Multi-modal
Sofia Metro	1998	2012	31.0 km	27	2: Red, Blue	81 Series/Metrovagonmash	52	450,000 (OFFnews, 2014)	0,42	1,63	No
Warsaw Metro	1995	2008	22.7 km	21	1: M1	81 Series/Metrovagonmash; Metropolis/Alstom; Inspiro/Siemens	40 x 6-coach trains	568,000 (Warsaw Metro, 2012)	1,32	4,90	Yes
Lisbon Metro	1959	2012	43.2 km	55	4: Blue, Yellow, Green, Red	ML90, ML95, ML97, ML99/Siemens	113 3-coach trains	422,000	1,00	4,80	Yes
Tyne and Wear Metro	1980	2002	74.5 km	60	2: Green, Yellow	Metrocar/MCCW	90 x 2-coach trains	97,800 (DfT, 2014)	From 1,80 to 3,30	From 2,60 to 4,50	Yes

4. CONCLUSIONS

The four metro systems presented in the paper show variety of approaches to system design, fleet operations and system operations in general. The examples show that a metro system is a long-term project, which delivery can span over a number of years and is dictated by financial conditions of an investor as well as political willingness for change and improvements of interested parties. As an investment in a new system is substantial, it needs to be well planned and budgeted. Usually, it takes a number of years, from day one of construction works to day of opening the system, to have a system up and running as originally designed. Examples from Warsaw and Sofia show that a slow but continuous development of a metro system, with new lines and stations opening, while the existing system is in operations, is possible. Moreover, expansions to the existing systems are considered and possible, as Tyne and Wear example shows. Multimodal tickets are getting more popularity as they

offer more flexibility to passengers in terms of using best public transport option available to serve their needs. Ticket prices are similar in three of the four systems presented, which is interesting, as Warsaw is NMS with a much lower GBP than the other two EU-15 countries described.

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