

This research found that adaptive signal systems reduce average intersection wait time by 30% and increase network capacity.

Real-world implementation will improve traffic control efficiency, reduce congestion, and increase road safety. Modern algorithms and tools are key to building future adaptive transport systems [3].

Future work focuses on signal cycle generation algorithms for program-adaptive control. These systems switch control modes based on time of day and day of week, enabling near-optimal performance under steady traffic conditions and moderate congestion (below 70%).

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DEVELOPMENT OF THE METRO

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Today, the metro is an integral part of many people's lives. But no one thinks about the history of this strange and fascinating mechanism. How did we get to the level we have now? The metro in different cities and countries are as diverse as the people who use them (or the cities in which the metro is located). They can look completely different: from Victorian tunnels, carved by hand, to the most modern underground structures with a fully automated system.

First appearing in the second half of the 19th century, the metro has become an integral part of modern life. Its emergence and development had a significant impact on the economy, urbanization and mobility of the population.

The year of birth of the metro is considered to be 1863, and the birthplace is London. For 27 years, the subway there operated on steam traction and since 1890 –

on electricity. Over time, this type of transport is gaining popularity not only in its homeland. A network of such highways appears in many large cities around the world. For a century and a half, the metro has been an integral part of megacities, both as a surprisingly effective way to relieve city streets of traffic and as a component of cultural life, with exhibitions, plays, performances, fashion shows and film shootings. And some stations have even become independent works of art – such as, for example, the Arts et Métier’s station of the Paris metro (French: Arts and Crafts) [1].

The birthplace of the first metro was London. In the middle of the 19th century, when the history of the metro was just beginning, there was a well-developed railway network in Great Britain: trains ran from the capital's stations to all sides of the island part of the empire. However, London's urban public transport was far from ideal - even from elementary convenience. Horse-drawn carriages slowly drove along the streets, and trains that brought passengers to London did not reach the City - the business center.

The idea to create underground transport was born at the right time: the reliability and relative convenience of such a connection was convincingly demonstrated by the tunnel under the Thames, opened in 1843. It became the first step in the history of the metro, which was based on the tunnel-passage shield invented in 1814 by the British engineer of French origin Marc Brunel - one of the most effective means of metro construction in general. The idea arose from observing a sea snail, a snail that used its shell to drill holes in the wreckage of sunken ships: in 1818, a patent was obtained for a mechanical copy of such a “worm”.

The metro in its modern form was developed by Londoner Charles Pearson, who in 1846 presented his project to the Royal Commission on Metropolitan Railways. In 1853, the North Metropolitan Railway Co was established, and in January 1860, with a significant delay due to financial difficulties, the first tunnel was dug in Easton Square.

On January 10, 1863, at 6 am, the main event in the history of subway construction took place - the launch of the first 3.6-kilometer subway line, which connected Farringdon Street and Paddington. There were 7 stations on the line, the trip

lasted 33 minutes.

Almost the entire city gathered for the opening of the station. The carriages had gas lighting – so bright, according to the Daily Telegraph, that it was possible to read the newspaper without difficulty. On the opening day, six coal-fired locomotives, filling the tunnel with smoke and steam (steam traction was replaced by electric only 30 years later, in 1890), pulled four carriages. Departures took place every 15 minutes: in the end, the trains made 120 trips in both directions, carrying 30 thousand passengers during this time!

The first electrified branch of the underground was, again, the London City South line, officially opened on November 4, 1890: then the Prince of Wales made the first underground journey from King William Street station to Oval station.

Many other cities followed London's example. In Budapest, a 4 km long electric metro was opened in 1896, using single-car trolleybus-mounted cars - the first metro on the European continent. Its construction achieved significant savings compared to earlier underground construction methods by using a flat roof with steel beams instead of a brick vault, and therefore a shallower trench.

In Paris, the metro (Chemin de Fer Metropolitan de Paris) began construction in 1898, and the first 10 km were opened in 1900.

In the United States, the first metro line appeared in Boston between 1895 and 1897. It was 2.4 km long and initially used streetcars, before switching to regular metro trains. In New York, the first section of what would later become one of the largest systems in the world opened on October 27, 1904. In Philadelphia, the metro opened in 1907, and in Chicago in 1943.

In Canada, the Toronto metro put into operation in 1954, and the second system was built in Montreal in the 1960s, using rubber-tire cars of the Paris type.

In Mexico City, the first phase of a combined underground-surface metro system (modeled after the Paris metro) opened in 1969. In South America, the Buenos Aires subway opened in 1913.

In Japan, the Tokyo subway opened in 1927, Kyoto in 1931, Saka in 1933, and Nagoya in 1957.

The first fully automated rapid transit system is the Bay Area Rapid Transit (BART) in the San Francisco Bay Area, which was completed in 1976. The trains are operated by remote control, requiring only one crew member per train in case of a computer failure.

The Washington, D.C. metro, with its automatic train control system and underground domed stations, opened its first metro line in 1976[2].

On November 6, 1960, the first metro line was opened in Kyiv with five stations: «Dnipro», «Arsenalna», «Khreschatyk», «University» and «Vokzalna».

But, in general, in Ukraine, or rather in Kyiv, the first project of an underground rail tunnel appeared back in the 1880s. But the construction of the metro was hindered by some factors. At first, the City Duma rejected the project, because: firstly, of the cost, and secondly, because at that time Kyiv there weren't problems with transport collapse. Then, the question of construction was returned to the 1910s. But again, the metro was not destined to start working in Ukraine, because of the First World War and the Civil War.

In 1936, a new General Plan for the development of Kyiv was approved. Construction of the government quarter began. In the same year, the project for the Kyiv Metro, about 40 kilometers long, was approved. In 1937, the construction began on two tunnels under the Dnieper: The Southern Tunnel, which would connect Zhukiv Ostrov with Osokorki, and the Northern Tunnel, to connect Obolon with Vygurivshchyna. But construction was halted due to World War II.

In the spring of 1945, a plan for the post-war reconstruction of Kyiv was approved. It provided for the construction of 22 stations on three metro lines that exist today: Svyatoshyn-Brovary, Kurenivka-Stalinka (now Obolon-Teremky), and Syrets-Pechersk.

By 1958, the tunnels, rails and escalators for the first five stations of the Kyiv Metro were fully laid - "Dnipro", "Arsenalna", "Khreshchatyk", "Universitet" and "Vokzalna".

Today, the Kyiv Metro consists of three lines with a length of almost 70 kilometers, 52 stations with three interchanges. The metro carries about 1.5 million

passengers daily[3]. the deepest metro station in the world - "Arsenalna" (105.5 meters), appeared due to the peculiarities of the soil, groundwater and other aspects.

The Kharkiv Metro is a modern transport enterprise in terms of its purpose and technical equipment, it is a complex of numerous engineering structures that ensure high-speed safe movement of trains and mass transportation of passengers [4]. Kharkiv became the second city in Ukraine where the metro was opened.

The metro itself has been operating since August 22, 1975 and consists of 3 independent lines with an operational length of 38.7 km, 30 stations with three interchanges, including:

- Kholodnohirsko-Zavodskaya line – 17.26 km (13 stations);
- Saltivskaya line – 10.46 km (8 stations);
- Oleksiivskaya line – 10.98 km (9 stations)[4].

The metro has always been a convenient mode of transport, and during the war it also became the safest.

For Kharkiv residents, the metro became a shelter from Russian bombs and missiles, the main safe location for everything in the frontline city. At first, in 2022, the metro acted only as a shelter, the stations turned into camps for those in need. People rallied: they sang, talked, supported each other, did not lose heart and were safe. The cars, like the stations, turned into sleeping places. Then, when the shelling subsided a little, people were able to return to their homes and the metro worked as before, but now free. But free travel is far from all that the Kharkiv metro can boast of.

Since many schools have now been destroyed by shelling, Kharkiv is introducing now-how - in 2023 the first metro school (and later kindergartens) was opened in the metro. Classrooms for over 2,000 students of Kharkiv schools are being equipped at 5 metro stations. Currently, metro schools continue functioning and already cover about 7.5 thousand students, providing safe conditions for learning in the underground space.

The Kharkiv metro also began to perform another function - it became the main place for holidays. Kharkiv, starting from the end of 2022, was the only city in Ukraine that began to hold New Year's holidays underground. The metro became the main festive venue for both New Year's and Christmas holidays with a Christmas tree,

illuminations and a concert program.

Since the beginning of its operation, the metro has changed and improved all over the world, keeping up with the development of the latest technologies. Lots of changes have occurred during its existence all over the World, mention should be made of some:

- The number of lines and stations has increased to cover remote areas of cities.
- Introduction of automatic train traffic control systems.
- Replacing paper tickets with more convenient electronic cards, mobile applications and NFC systems.
- Equipping stations with elevators and lifts for passengers with reduced mobility.
- Automated trains without drivers (although, so far, this practice is not widely used).
- Digital displays with train arrival schedules.

Conclusion

The development of metro systems has played a vital role in transforming urban transportation by providing fast, efficient, and environmentally friendly travel options. As cities continue to grow, investment in modern, sustainable metro networks becomes increasingly important. With advancements in technology and urban planning, metro systems will remain essential to meeting the demands of future urban mobility.

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