

DEVELOPMENT AND RETROSPECTION OF THE INNOVATIVE TECHNICAL SOLUTIONS

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Abstract. Often infrastructure projects in an urban environment come into conflict with each other due to the limited urban space and the large number of different development programs and the large number of funding sources. The accumulation of such type of problems can be solved through the integration of infrastructure projects. This article aims to compare the different types of integration (simultaneous, parallel and sequential) in terms of project scope, construction technology and duration. Through the use of methods of qualitative analysis and quantitative analysis, two separate projects from the construction of the III metro diameter of the metro in Sofia, built on one site, with the different types of integration of management and construction will be analyzed. The research results unequivocally show the superiority of the integrated management and implementation of the infrastructure projects over the non-integrated one.

Keywords: infrastructure projects in an urban environment; Sofia metro; integration of infrastructure projects; quantitative analysis; qualitative analysis.

1. TRANSPORT SITUATION IN THE CAPITAL OF THE REPUBLIC OF BULGARIA

Table 1. Transport situation in Sofia – overview.

Population of Sofia city towards 2012 along with the temporary residents	More than 1,6 million people
Traffic congestions	Every day along the most loaded directions
Number of cars towards 2022	More than 900 thousand cars
Duration of trips by public transport in rush hours from suburbs to city center	Over 40–60 minutes
Duration of trips by metro in rush hours from suburbs to city center	10–15 minutes

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Speed by public transport in rush hours	10–14 km/h
Speed by metro, incl. waiting for train, boarding, travel and alighting	35–38 km/h (with maximum allowable speed of 80 km/h)
Average transport capacity of the public transport lines	4–5 thousand pass/h tram – 8 thousand pass/h
Average transport capacity of the Sofia metro	40–50 thousand pass/h
Existing loads along the main directions	18–30 thousand pass/h
Maximum future passenger loads	38 thousand pass/h

The above necessitated the start of construction of the metro in these directions.

2. BASIC INFORMATION ABOUT THE METRO LINES IN SOFIA

According to the General scheme for the development of metro lines in Sofia, it should have three diameters with a total length of 76 km, 71 metro stations and an estimated number of carried passengers over 800 thousand passengers per day.

- First line is 32 km long and has 28 stations.
- Second line will have a length of 23 km and 22 stations.
- Third line will have a length of 21 km and 21 metro stations.

The lines are crossing one to each other in a triangle in the central part of the city, thus with one transfer you can reach any part of the metro route. The above lengths reflect the development of the lines in a long-term perspective outside the city center with the planned branches in these sections, and in their final phase they will have an X-shaped structure. After the implementation of these extensions, the metro will carry out its transport work along 6 routes, and its share in the public transport system will exceed 60%.

In January 2023 the Sofia Metro is 52 km long and has 47 stations distributed as follows:

- Line 1 – 27 km with 22 stations.
- Line 2 – 13 km with 12 stations.
- Line 3 – 12 km with 12 stations.

At the end of 2026, the total length of the lines should reach 61 km with 56 stations, and the extension during this period is only on Line 3, which will reach 21 km with 21 stations.



Fig. 1. Scheme of the development of the lines of Sofia Metro

3. BASIC TECHNICAL PARAMETERS OF THE METRO IN SOFIA

- average distance between stations – 1100 m (L1), 1000 m – L2 and L3;
- operating speed of the rolling stock – 80 km/h (90 constructive);
- minimum permissible interval between trains – 90 sec.;
- gauge – 1435 mm;
- supply of the rolling stock with direct current with a nominal voltage – 825 volts through a third rail – Line 1 and 2 and 1500 volts through an upper contact wire with a rigid supporting aluminum profile – L3;
- length of metro station platforms – 105 m;
- minimum platform width: 10 m island and 4 m side platforms;
- maximum transport capacity of 50 thousand passengers per hour in one direction with a train length of 100 m (40 thousand passengers/hour at 80 m, 30 passengers/hour at a length of 60 m);

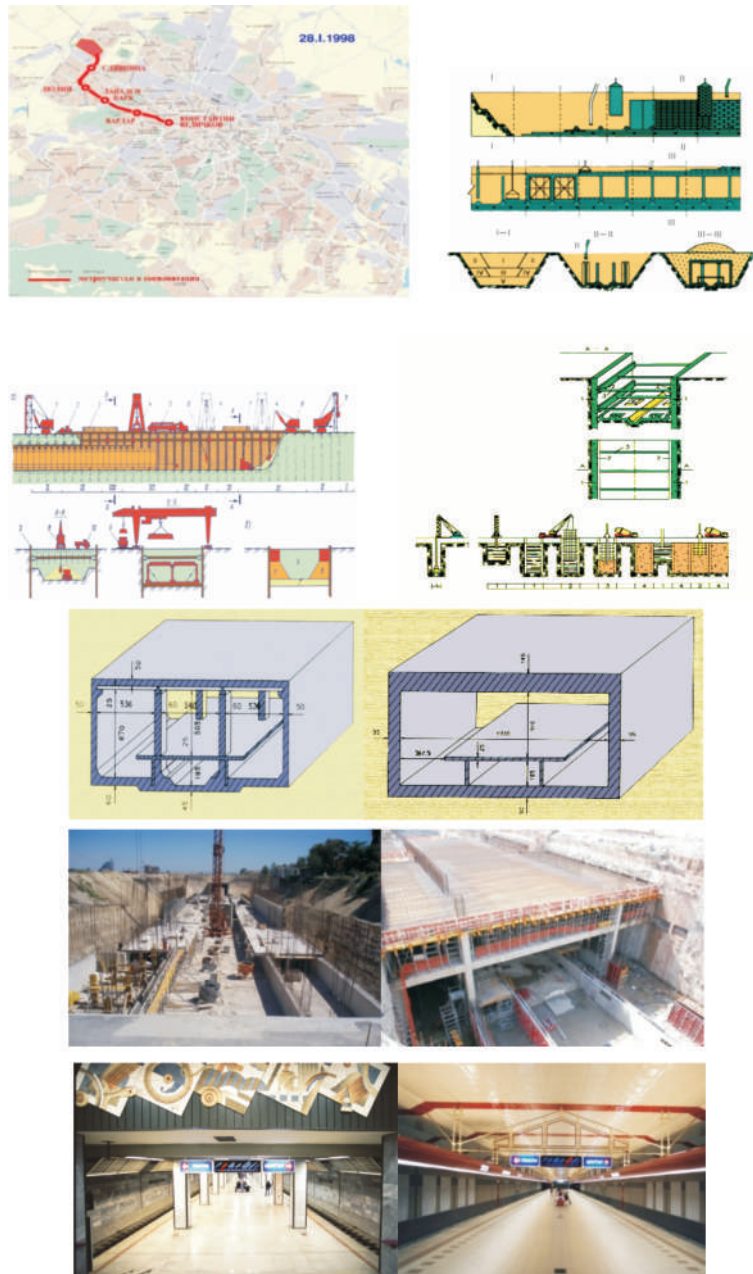


Fig. 2. Schemes of: section; construction technologies; stations' structures and general view of the construction and of the completed stations MS Lyulin and MS K. Velichov

- maximum passenger flows in the direction of the metro lines with a 30-year growth perspective: Line 1 – 38 thousand people/h.; Line 2 – 24 thousand people/h.; Line 3 – 28 thousand people/h.

4. CONSTRUCTION AND COMMISSIONING OF THE DIFFERENT SECTIONS OF SOFIA METRO

4.1. Line 1

4.1.1. *First operational section (construction – 1979–1998) “MS Slivnitsa – MS K. Velichkov” and metro depot “Obelya”*

- Length – 6.4 km Number of metro stations – 5 pcs.
- Duration of construction – 19 years.
- Method of construction – cut-and-cover in sloped trenches and in reinforced trenches. Contractors: “Metrostroy” OF, “Inzhstroy” OF, Transstroy with Commissioning Management, etc. Designer: OF “Metroproject”.



Fig. 3. Scheme of the first metro radius of Line 1. Construction and general view of stations MS Serdica and MS Obelya – commissioned 1999–2003

4.1.2. Section: MS K. Velichkov – MS Serdica (construction: 1999–2000) and MS Slivnitsa – MS Obelya (construction: 1986–2003)

- Length 3.8 km.
- Number of stations – 4.
- Method of construction – cut-and-cover in trenches with slopes and on the ground level.

Constructors: MC Metrostoy, MC Inzhstroy, Transstroy with subcontractors Puskovonapadachno upravlenie, RT, etc. General Designer – MC Metroproekt.

4.1.3. Section MS Serdica – MS Mladost 1 (construction: 2004–2009)

- Length – 8 km.
- Number of stations – 6.
- Methods of construction:



Fig. 4. Scheme of Line 1 in 2009. Tunnel Boring Machine 6 m of diameter for the construction of tunnels in section MS Serdica – MS V. Levski Stadium. View od MS SU St. Kl. Ohridski

Tunnel sections: Shield method (section MS Serdica – MS V. Levski Stadium);

New Austrian Tunneling Method (NATM) (Section MS V. Levski Stadium – MS J. Currie);

Cut-and-cover in trenches with slopes and on the ground level (section MS J. Currie – MS Mladost 1);

Stations – Top-down Method, cut-and-cover in trenches with slopes and on the ground level (MS Musagenitsa).

Constructors: Taisei – Japan, Geotechmin, Stanilov Ltd , Trace Group Hold, BCS Centre with sub-contractors GBS, Transstroy, Startengineering, ITA Engineering, etc. Designers: MC Metroproekt, BIAS – M, Injproekt.

4.1.4. Section MS Mladost 1 – MS Airport/MS Mladost 1 – MS Tsarigradsko Shose (construction – 2009–2012)

- Length – 7.2 km.
- Number of stations – 6.
- Method of construction: cut-and cover on the ground level and on trench; NATM.
- Cut-and-cover in trenches with slopes; cut-and-cover in trench strengthened by sheet piling.



Fig. 5. Scheme of the route MS Mladost 1 – Airport. Construction and view of MS Mladost 3 and MS Tsarigradsko Shose 2009–2012



Fig. 6. Construction of the tunnel in section Tsarigradsko Shose – Airport in a trench strengthened by sheet piling. Scheme of the structure and general view of the ground stations – MS Sofiyska Sveta Gora and MS Airport

- Top-down method.
- Financing: OP Transport 2007–2013 with local cofinancing.
- Constructors: Trace Group Hold, Stanilov Ltd, Sienit with sub-contractors: Euroaliance, Valmex, ABB, Startengineering. Designers: Injproekt, BIAS – M, Serafimovi.

4.1.5. Section MS Mladost 1 – MS Business Park (constuction – 2012–2015)

- Length – 3 km.



Fig. 7. Construction and view of MS Al. Malinov and MS Business park

- Number of stations – 3.
- Method of construction: Cut-and-cover in trenches with slopes; Top-down method. Cut-and-cover in a trench strengthened by diaphragm walls, included into the structure.
- Financing: OP Transport 2007–2013 with local cofinancing.
- Constructors: Geostroy, Interprom, GP Group with sub-contractors: ITA Engineering, Startengineering, Euroaliance, Valmex. Designers: BIAS – M, Startengineering, ITA Engineering.

4.2. Line 2

4.2.1. Section Nadezhda – Lozenets (2008–2012); Section MS James Bourchier – MS Vitosha (construction – 2014–2016)

- Length 12 km.
- Number of stations 12.
- Method of construction: On overpass.
- Cut-and-cover in a trench strengthened by diaphragm walls, included into the structure, Top-down method.
- Shield method using a TBM with contra pressure in the face.
- New Austrian Tunnel-boring Method (NATM).
- Financing: OP Transport 2007–2013 with local cofinancing.
- Constructors: BKS Center, JP Group, Stanilov Ltd, Trace Group Hold, Dogus, with sub-contractors: Startengineering, Transstroy, ITA Engineering, Dendrit, Balfour Beatty, Valmex, Euroalliance.
- Designers: BIAS – M, RIKAT, Dogus-Nicola De La Vale (Italy – design of tunnel by TBM).



Fig. 8. Situation of Line 2 in the urban planning. Scheme and construction under the Top-down method. View of MS Lavov Most

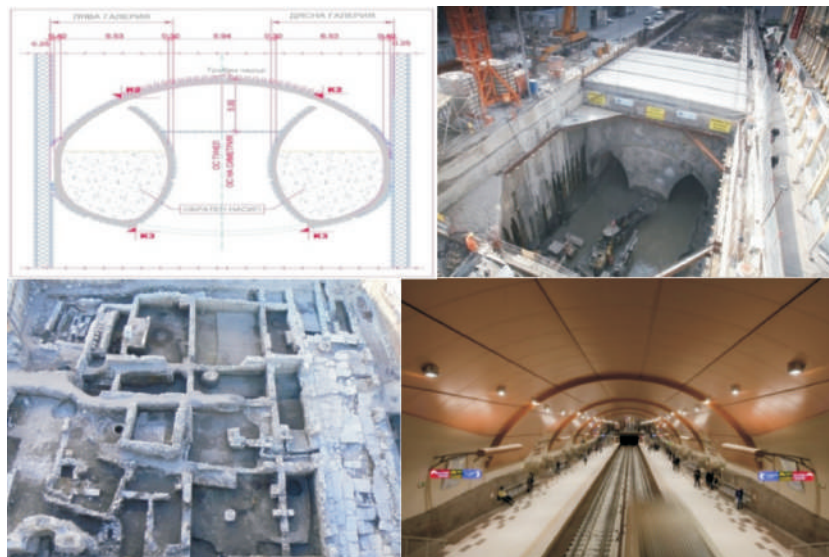


Fig. 9. Scheme and construction under the modified NATM of MS Serdica 2. Archaeological findings above the arch and view of the station



Fig. 10. Construction and view of MS European Union. Tunnel Boring Machine for the construction of the double-road tunnel and a view of the finished tunnel in the central section of Line 2

4.2.2. Elements of the basic equipment of Lines 1 and 2



Fig. 11. Dispatch control and rolling stock of Lines 1 and 2 of the metro in Sofia



Fig. 12. Protective vertically opening screen doors between the platforms and the tracks (trains). These are installed at 12 of the busiest stations on Line 1

4.3. Line 3



Fig. 13. Scheme of the development of the 2nd and 3rd lines of Sofia Metro

4.3.1. Line 3: Stage 1: Section MS Hadzhi Dimitar – MS Krasno Selo (construction – 2016–2020)

- Length – 8 km.
- Number of stations – 8.
- Methods of construction: Tunnels – TBM – 6.5 km; NATM – 0.7 km, Metro Stations – modified NATM – 1 station.
- Top-down – 5 stations; Top-down plus Cut-and-cover method – 2 stations.
- Start of construction – 2016.
- Completion – 2020.
- Financing – OPTTI 2014–2020 and local co-financing.
- Constructors: Trace Group Hold, Interprom, Siemens, JP Group, Monolit, Dogus, Balkanstry with sub-contractors: Startengineering, ITA Engineering, Dendrit, Panasonic, Hydroinject, Bauer, Euroaliance. Designers: Inzhproekti, RIKAT, BIAS – M, Nicola De La Vale (Italy – design of tunnel by TBM).



Fig. 14. Construction of MS Orlov Most under the modified NATM and view of the completed station. Construction of MS NDK 2 under the Top-down method and view of the station

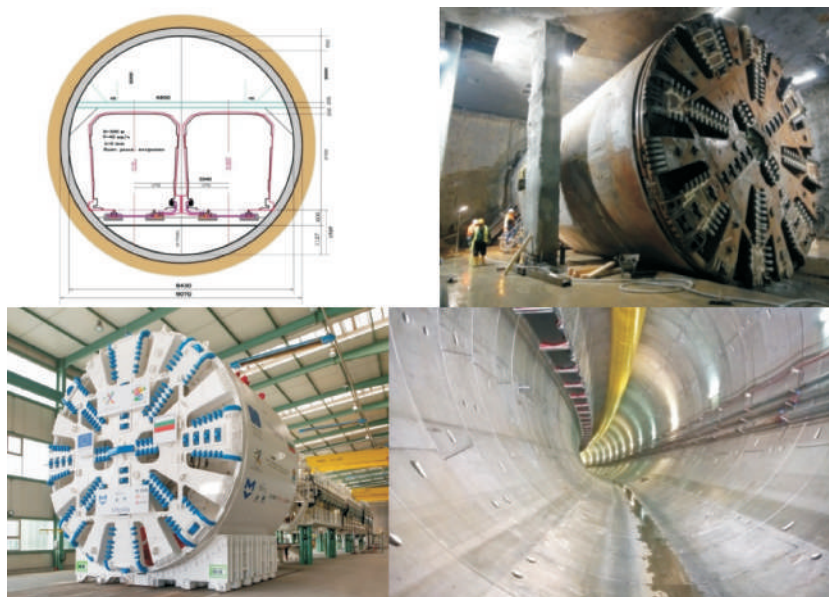


Fig. 15. Scheme of the double-road tunnel, TBM and view of the completed tunnel of central part of Line 3

4.3.2. Line 3, Stage 2: Section MS Krasno Selo – MS Gorna Banya (construction – 2017–2021)

- Length – 4 km.
- Number of stations – 4.
- Methods of construction: Tunnels – NATM – 0.7 km; Top-down method – 1.9 km; Cut-and-cover method – 0.8 km.
- Metro Stations: Top-down and Cut-and-cover methods – 4 stations.
- Start of consruction – 2017.
- Completion – 2021.
- Financing – OPTTI 2014–2020 and local co-financing.
- Constructors: Trace Group Hold, Obonato, Interprom, Siemens with sub-contractors: Dendrit, PT, Panasonic, Startengineering, Geostroy, ITA Engineering, Euroaliance, Valmex, Hydroinject.
- Designers: Inzhproekti, RIKAT, BIAS – M.



Fig. 16. Construction scheme, construction process and view of the completed MS Ovcha Kupel and MS Ovcha Kupel 2

4.3.3. Some elements pf main equipment of Line 3



Fig. 17. Dispatch Control, platform screen doors, Zemlyane depot and rolling stock

4.3.4. Average comparative parameters for the value of the experience in the construction of the completed sections of the tunnels and metro stations of the Sofia Metro

Stations:

- At the level of the field 60% (in case there is terrain and town planning possibility).
- On overpass – 80% (in case there is terrain and urban planning possibility).
- In a trench with slopes – for the purposes of comparison, a value of 100% is accepted.
- In strengthened trench with the inclusion of reinforcement in the structure – 112%.
- Under Top-down method with the inclusion of reinforcement in the structure – 118%.
- Under Top-down method with internal structure – 135%.
- In strengthened trench with an internal structure (without including the reinforcement in the structure) – 135–140% (using strengthening with piles or with diaphragm walls).

According to a modified NATM with development of the section and building the structure by parts – 160%.

Sections between stations and tunnels:

- On terrain level – 45%.
- On overpass – 75%.
- In a trench with slopes – for comparison purposes, a value of 100% is accepted.
- Under Top-down method without internal structures – 115%.
- Under Cut-and-cover method with the inclusion of strengthening in the structures – 120%.

- Under Top-down method with internal structures – 130%.
- Under Cut-and-cover method in strengthened trench with an internal structures – 135–140% (using strengthening with piles or with diaphragm walls).
- Under New Austrian Tunneling Method – 140%.
- Under Shield method with TBM with counter pressure in the face – 180–210%.

5. ONGOING AND UPCOMING EXTENSIONS OF THE SOFIA METRO (LINE 3) 2022–2026



Fig. 18. Situation in the urban planning of the ongoing and upcoming extensions of Line 3 – 2022–2026

5.1. Section Hadzhi Dimitar district – Levski district (construction – 2022-2025)

- 3 km long with 3 metro stations and buffer parking above the turnover facility for changing the direction of trains after the metro station in Levski area.
- Methods of construction: Cut-and-cover method and Top-down method for the metro stations and Top-down and NATM for the tunnels.
- Financing – from the Recovery and Resilience Plan. Under construction since the first quarter of 2022. Completion – mid 2025.



Fig. 19. Implementation of the MS G. Asparuhov Stadium and Conceptual design for the platform of the station

5.2. Section Shipka Str. – Geo Milev district – Slatina – Tsarigradsko Shose Blvd. (planned construction – 2023–2026)

- 6 km long with 6 metro stations and buffer parking on Tsarigradsko Shose Blvd. above the puller turnover facility for changing the direction of trains after the metro station on Tsarigradsko Shose Blvd.
- Methods of construction: Cut-and-cover method and Top-down method for the metro stations and Shield method using a Tunnel Boring Machine with counter-pressure in the face for the entire double-road tunnel.
- Financing – Loan to SM from EIB, local co-financing and state budget. Planned start of construction – 2023.

6. PUBLIC BENEFITS AND INTERMODAL CONNECTIONS OF THE METRO IN SOFIA AFTER THE COMPLETION OF LINE 3 (SHORT-TERM PERSPECTIVE 2025/26)

Table 2. 6. Public benefits and intermodal connections of the metro in sofia after the completion of line 3

Public Benefits	2012 Stages 1 and 2 of Line 1 and Line 2	2016 Stage 3 of Line 1 and MS 12 of Line 2	2021 Stages 1 and 2 of Line 3	2026 Stage 3 of Line 3 Lot 1 and Lot 2
Lines Length	31 km/ 27 MS	40 km/ 35 MS	52 km/ 47 MS	61 km/ 56 MS
Number carried passengers (th. pass.daily)	260	340	400/440 – 10 years	Over 550/650 – future
High transport capacity	50 th pass./h			
High transport speed	Up to 80km/h			
Time to reach the city center	10–18 min.			
Share in the public transport system (perspective)	18%	30%	Over 38%	Over 46%
Traffic reduction	18%	25%	25%	25%
Reduction of traffic accidents	12%	18%	25%	30%
Links to the railway system	1	2	3	4
Links to tram lines	9	10	14	18
Links to busses and trolleybuses	31	37	Over 55	65
Reduction of harmful gasses (th.tones annually)	30 th.t./y	59 th.t./y	79 th.t./y	90 th.t./y
Reduction of cars	45 th./daily	65 th./daily	95 th./daily	114 th./daily
Saved time of the citizens	95	120	160	210

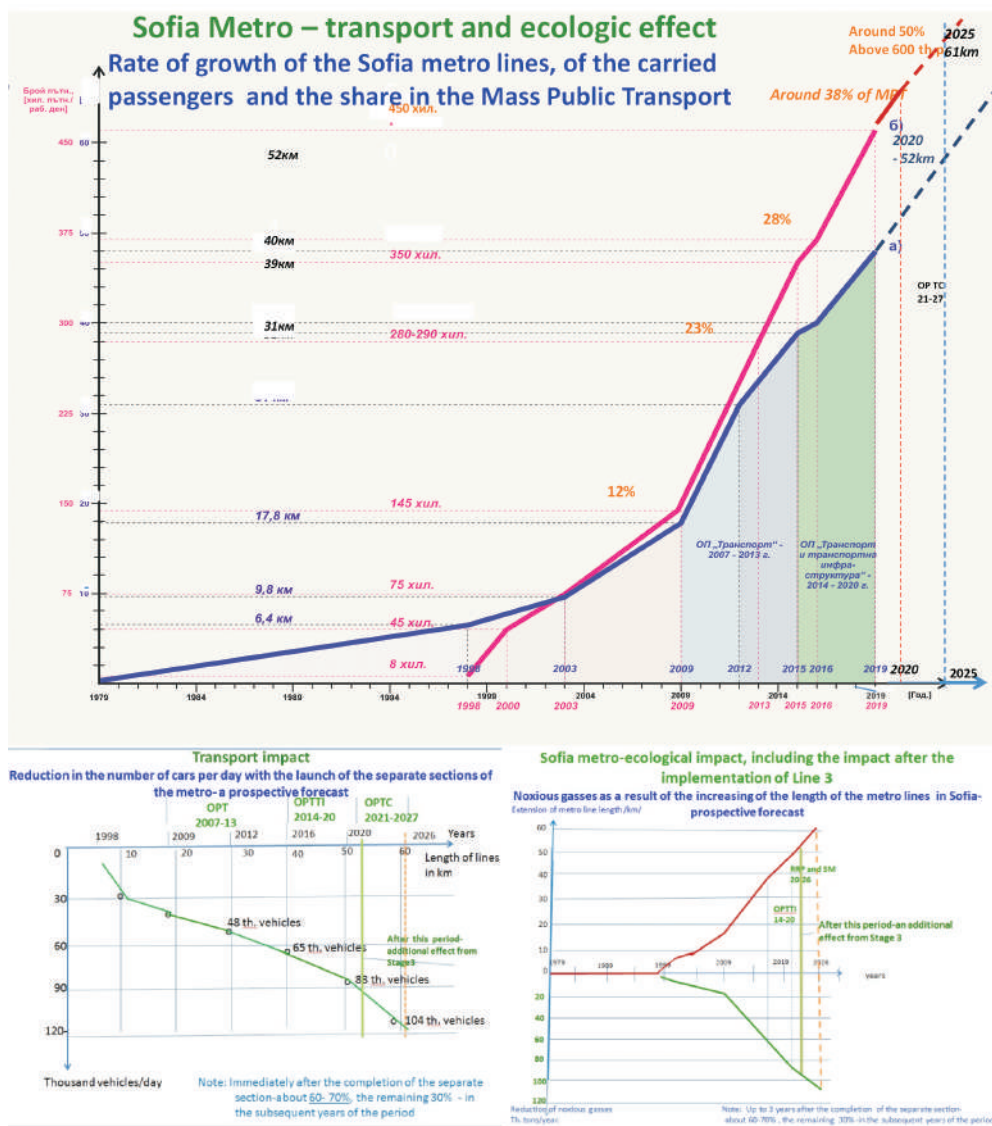


Fig. 20. Transport effect, reduction of the number of cars and harmful gases after the completion of different sections of the metro in Sofia

7. POSSIBLE FUTURE EXTENSIONS



Sofia Metro Extension implemented under OPTTI 2014–2020

Line 3 reaches 54 km after completion of Stage 1 and Stage 2 (green line)
Dashed green lines are Stage 3, Lot 1 and 2, which will be implemented in the period 2021 – 2025. After completion the metro will reach 61 km with 56 stations and over 200 mln passengers annually.

Fig. 21. Scheme of the metro lines in Sofia in 2022 with upcoming extensions (solid green dashed line) and possible perspective extensions – the thin lines

a) Line 1:

- Section MS Lyulin – Ring Road towards Bozhurishte – 1.8 km with 2 stations.
- Section MS Business Park – Ring Road (lower lift station of the Simeonovsky lift) – 1.8 km with 2 stations.

b) Line 2:

- Section MS Vitosha – Ring Road towards Dragalevtzi – 2 km with 2 stations.
- Section Cherni Vrah blvd. – Studentski Grad – 4 km with 4 stations.
- Section Nadezhda Overpass – Ilentsi district – 5 km with 4 stations.

c) Line 3:

- Section MS Krasno selo (deviation after the Zemlyane depot) – Ring Road (in the direction of Boyana district) – 4 km with 4 stations.

Thus, in the long run, all three diameters will have an X-shaped structure by two lines each, or a total of 6 lines. In conclusion, it can be said that the operating until 2023 metro lines in Sofia of 52 km with 47 metro stations, after the completion of the two upcoming stages of Line 3 with 9 km with 9 metro stations, in 2026 will reach 61 km with 57 metro stations (incl. intermediate metro station between Slivnitsa and Obelya metro stations). The total length of the metro lines in Sofia after the implementation and the possible long-term extensions will amount to 76 km with 71 metro stations and a share in the Mass Public Transport system will exceed 56% (Fig. 18). These long-term extensions can be supplemented or corrected depending on the direction of the city's development, respectively depending on the passenger loads along them.

Finally, I would like to express my gratitude to the principal managers of the contractor companies: Eng. Y. Sokolov, Eng. N. Topalov, Eng. G. Karov, Eng. S. Peshov, Eng. D. Ninov, Eng. Botusharov, Eng. V. Vasilev, Prof. Dr. Ts. Vutov, Dr. Eng. V. Vutov, V. Zhitinski, St. Totev, Eng. B. Krapchev, engineer I. Tasev, N. Kaloyanov, Eng. K. Petkov and others. I would also express gratitude to the heads of the design companies and teams: Eng. Chuchkov, Arch. Ch. Pavlov, Eng. St. Filipov, Eng. M. Manev, Eng. K. Konstantinov, Eng. Otashliyski, Eng. M. Dimitrova, Eng. L. Iliev, Eng. A. Yanev, Arch. K. Kosev, arch. Kr. Andreev, arch. I. Derlipanska, arch. E. Paktiaval, arch. F. Paktiaval, arch. R. Serafimov, arch. D. Mushev, arch. Sl. Galabov and others. Directors and main managers in Metrolipiten JSC with a contribution to the design, construction and operation of the metro are the following: eng. V. Vasilev, engineer K. Kamenov, engineer K. Feradov, Eng. St. Stamenov, Prof. Dr. Eng. St. Bratov, Eng. St. Dermendzhiev, Eng. K. Zaikov, Eng. O. Georgiev, Dr. Eng. A. Dzhorgov and others.

In the last 12 years, the implementation of the extension of Line 1 and the construction of Lines 2 and 3 of the metro by a total length of 34 km has been significantly helped by the inclusion of metro projects in OP Transport and OP Transport and Transport Infrastructure, and for the delivery of additional ecological vehicles - metro trains – OP Environment with funding from the Cohesion and Regional Development Fund of the EU. This financing for the scale of the country is essential for the realization of the unique object for the capital – the metro in Sofia. In this regard, I use the opportunity to express my gratitude to the representatives of the directorates of the European

institutions involved in the Operational Programs, to the Heads of Ministry of Transport, Informational Technologies and Communication and the Ministry of Education and Culture, and to the Governing Bodies of the Operational Programs in these ministries.

I also use today's anniversary to express my gratitude to the mayors of Sofia during the various years since the beginning of construction, who, according to the city's capabilities during the different periods of time, considering the metro as a priority object for the city, have significantly supported its 52 km development – starting with the mayors St. Ninov, P. Mezhdurechki, Prof. A. Yanchulev, St. Sofianski and reaching the great progress of the site of over 42 km after 2005 during the time of B. Borisov and Y. Fandakova.

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