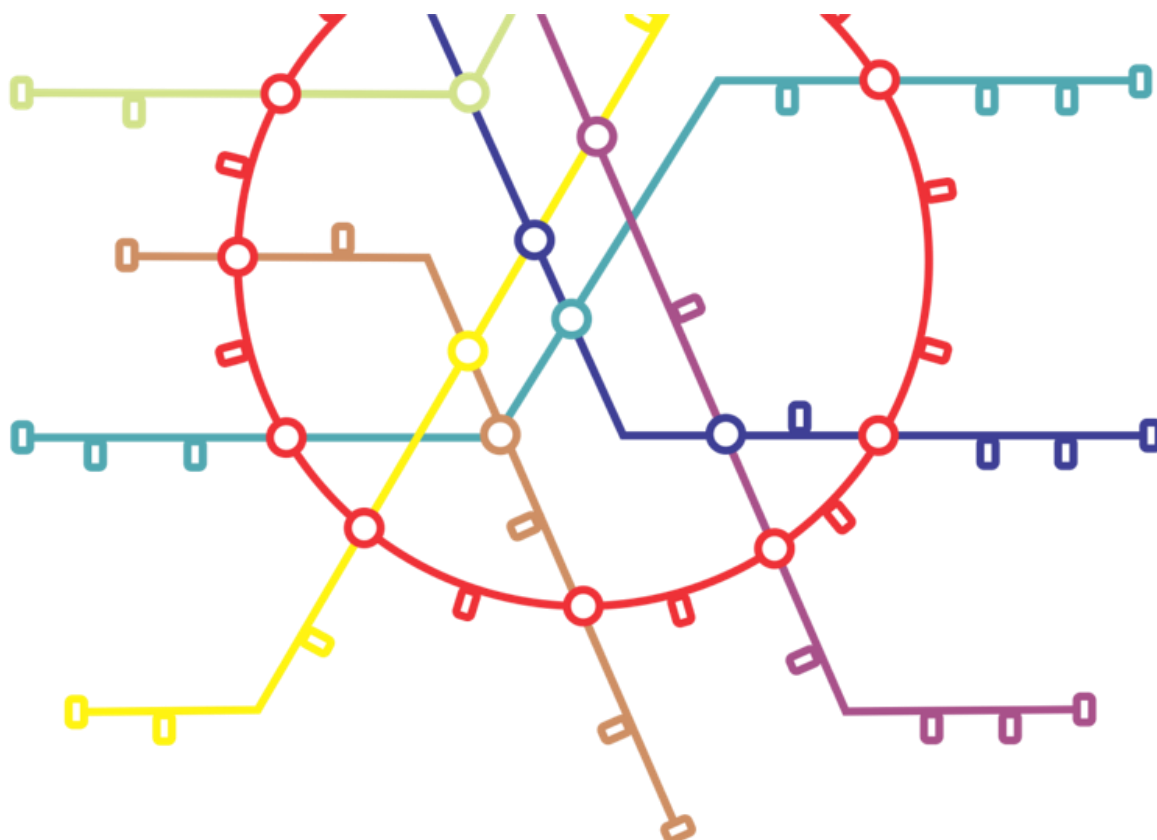


DEVELOPMENT OF BUS LANES AND SEPARATE INDEPENDENT ROUTES IN PUBLIC TRANSPORT PROJECT



SUMMARY

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OCCASION, GOALS AND TASKS OF THE STUDY-DEVELOPMENT PROJECT

The realization of mobility is accepted as one of the most significant needs of an urban area's population. The technology of mobility realization has a direct impact on the sustainable development and quality of life in a city, which are primarily implied by the time spent within the transport system and through the satisfaction of different social and economic requirements.

For the reasons outlined above, operation optimization of cities and their transport systems is a complex and demanding task with far-reaching effects in all areas of the lives of their citizens. In the European Union accomplishing the goals of sustainable development and quality of life in regards to transport systems is accomplished through a policy based on the principle of realizing citizen mobility with a limited use of automobiles. For this reason, one of the most important decisions in the process of planning for efficient urban transport systems considers the selection of public passenger transport subsystems and their operational efficiency.

The development of a public transport system should aim to raise the quality of the transport service, and maintain and increase its participation in the transport mode distribution within the city transport system, which in turn directly affects sustainable development and preservation of quality of life.

One of the basic elements of the structure of the urban public transport system is the network of lines which, through its performance, represents the basis of the transport offering of the system. The efficient operation of the line network is one of the basic prerequisites in the process of creating a quality and efficient public transport system.

The line network depends on the structure of the city, the city transport network and its infrastructure (road network), the structure of the public passenger transport system in terms of subsystems, the characteristics of the geography and climate of the urban area, etc.

Today, the greatest challenges (and their causes) which affect the efficiency and quality of line network operation are external in nature, and occur predominantly as chronic traffic congestion in certain parts of the network, producing time loss in the system and directly causing loss of transport service quality and loss of the system's attractiveness.

At this point in time, the city of Belgrade has a very well-developed public transport system, with a wide network of 514 urban and suburban lines with multiple modal subsystems of the public passenger transport system (minibus, bus (conventional and e-bus), trolleybus, tram, suburban railway)¹.

Annually, 600 million passengers use the public transport system on workdays, which in modal distribution constitutes 50% of the total journeys made within the urban transport system. These facts points to the public transport system as the most significant service for the mobility of the citizens of the city of Belgrade.

On the other hand, operating speeds in public transport system in Belgrade are relatively low at about 13 km/h. This significantly reduces the efficiency, productivity and attractiveness of the system as well as its competitiveness compared to other modes (primarily automobiles and the like).

¹Total number of lines and daily and nightly operation modes.

As an efficient answer to these challenges common to systems around the world, contemporary trends in urban transport system planning postulate prioritizing vehicles of the public transport system in the urban network.

The measures for prioritizing public transport system vehicles mostly refer to the use of so called conventional technologies such as construction of a separate infrastructure solely for vehicles of the system (A and B type routes)², reserving independent surfaces for public transport system vehicles along the routes or sections of the line and/or prioritizing system vehicles at characteristic (critical) points, mostly through separate light signalization or use of vehicle announcement technologies (C type route)³, etc.

Apart from these priority measures the Secretariat for Transport, according to the provisions of the Road Traffic Safety Law, also performs technical traffic regulation and uses traffic cameras to perform analysis and process parameters of the traffic flow. The control of traffic regime and signalization adherence is under the jurisdiction of the Ministry of Internal Affairs, which is developing models for recording violations by use of video surveillance as part of the “Smart City” project, in cooperation with the Communal Police.

To make the public transport system of Belgrade more efficient and productive in the future, it is necessary to answer multiple questions of a plural nature. The key issues concerning the operation of the system (and especially the bus subsystem as the key subsystem in Belgrade)⁴ pertain to the elements which are an integral part of the system management, particularly concerning the task of creating conditions in which the system can function with minimal interference from its environment, i.e., interaction of the system and its external surroundings (external interference).

Likewise, important questions arise concerning the kinds of involvement and distribution of authority of the city’s professional institutions (primarily the Secretariat for Transport and Secretariat for Public Transport) in the aspects of planning, design, implementation, coordination, and prioritization in the public transport system (“Priorities System”), the scope of priority application, primarily in the domain of right and time of use priority. Likewise, an important aspect is the spatial distribution of priorities in the city road network and their acceptability for other city transport system users (automobile users, bicycle users, pedestrians, etc.).

(Out of these considerations arose the need for the preparation of this research and development project (DEVELOPMENT OF BUS LANES AND SEPARATE INDEPENDENT ROUTES IN PUBLIC TRANSPORT PROJECT – BeoPiS) by applying a systemic approach to the analysis and planning of priority systems. The essence of the systemic approach is in the uninterrupted observation and determination of the interconnections between all the processes, sub-processes and activities within the structure of the system and their interaction with their environment with the aim of producing the desired scope and quality of the transport service. The focus on shaping the entirety of the system is a basic postulate of

² Type A route or so-called separate route for public transport vehicles is a fully controlled route without at-level intersections or any kind of use by other modes of transport. This route can be surface, underground or aboveground.

Type B routes are roads for public transport vehicles which are longitudinally physically separated from other traffic (by curbs, fences, split levels, etc) but with at-level intersections with other dynamic traffic.

³ Type C routes are roads with mixed traffic where public transport vehicles share the fate of the traffic flow with other dynamic traffic. On this type of route public transport vehicles can be assigned priorities (bus lanes, special light signalization, etc.).

⁴ Public bus subsystem lines serve the continuously built-up urban area (10 urban municipalities), the suburban municipality of Surcin, and the larger portion of Grocka municipality (more than 1,4 million citizens of Belgrade, i.e. 85,7% of the total population of the City of Belgrade).

the theory of systems and differs from the classic approach which is directed towards the shaping of structural elements, i.e. subsystems.

The aim of this project is a systemic analysis of the functioning of the public transport system in Belgrade with a focus on the existing conditions of the system for the prioritization of public transport vehicles (bus lanes, independent routes and separate light signalization), the analysis of congested corridors and sections of line routes in the urban transport network in the city centre area with suggested measures to improve the operation of the prioritization system. Apart from the central goal this research and development project has other aims the most significant of which are:

- Creating conditions for the improvement of the operation and productivity of the public transport system and the level of quality of transport services through increase in regularity, timeliness, and reliability of the realization of the proposed timetables and reduction in time losses of passengers and operators alike;
- Reduction of traffic congestion on identified critical sections of the line network. Typical causes of timetable disturbance in the Belgrade public transport system are a complex traffic situation in the city transport network (congestion), (non)coordination of the operation of light signalization, variations of transport demands in space and time, etc;
- An increase of the operational speed in the public passenger transport system. The prioritization system reduces variations in journey time between automobile trips and public passenger transport trips (thereby reducing the total journey time), which causes the optimization of transport capacities, i.e. a reduction in the number of vehicles operating in the line network and consequently a reduction in the cost of the entire system;
- A reduction in air pollution and an increase in the ecological suitability of the public transport system. Fewer stops and reduced time loss (primarily through the loss of stalled time) are direct consequences of the prioritization system and advanced system management techniques and technologies;
- More rational use of propulsion energy and an increase in the economic, energy and cost efficiency of the public transport system;
- An increase in quality of the transport service with an increase in efficiency and productivity of the Belgrade public transport subsystems;
- An increase in the quality of service and attractiveness of the system as a whole;
- Reduced driver stress;
- Promotion of public transport system use;
- Traffic safety improvement;

From these goals arise the tasks of this research and development project which are in line with the client's Terms of Reference, and they are as follows:

- Analysis of the current state of the prioritization system;
- Analysis of congested corridors and sections of line routes in the network in the central area of the city.
- Analysis of characteristic experiences concerning the introduction of the prioritization system to the line network of the public transport system;
- Defining criteria for the introduction of basic prioritization systems on the line network (bus lanes and independent routes);
- Defining proposed improvements to the existing basic prioritization systems in the line network;
- Simulation of proposed solutions and impact assessment within the existing Belgrade Transport Model;
- Analysis of the effects of proposed solutions;
- Defining the implementation dynamic in the actual system;

This research and development project has been prepared in four interconnected books, each of which represents a separate unit, as follows:

Book 1 – Methodology for the preparation of the research and development project,

Book 2 – Analysis of the existing condition of bus lanes in Belgrade,

Book 3 – Defining criteria and the proposed expansion of bus lanes in Belgrade,

Book 4 – Simulation of proposed solutions within the transport model of Belgrade.

BOOK 1 - METHODOLOGY FOR THE PREPARATION OF THE RESEARCH AND DEVELOPMENT PROJECT

Bearing in mind the subject and goals of the project implementation, a specific and original methodology has been designed, taking the postulates of system engineering as its basis and the “bottom up” approach (systemic requirements arise directly from the needs of interest groups), and modelling based on the methods, techniques and tools of the transport engineering field.

Given that the public transport system is a very important subsystem in the city transport system and the most significant service for the mobility of the citizens of Belgrade, we believe that this project will represent an important document for the future development of the city of Belgrade and have great significance for experts undertaking future development of the public transport system in Belgrade.

The methodology includes three phases:

- **PHASE I** – Preparation of the implementation of the research and development project
- **PHASE II** – Analysis of the existing subsystem condition within the public transport system
- **PHASE III** – Improvement of the existing prioritization system within the public transport system

The following image shows a detailed methodological process for the planning and design of the taxi system in Belgrade.

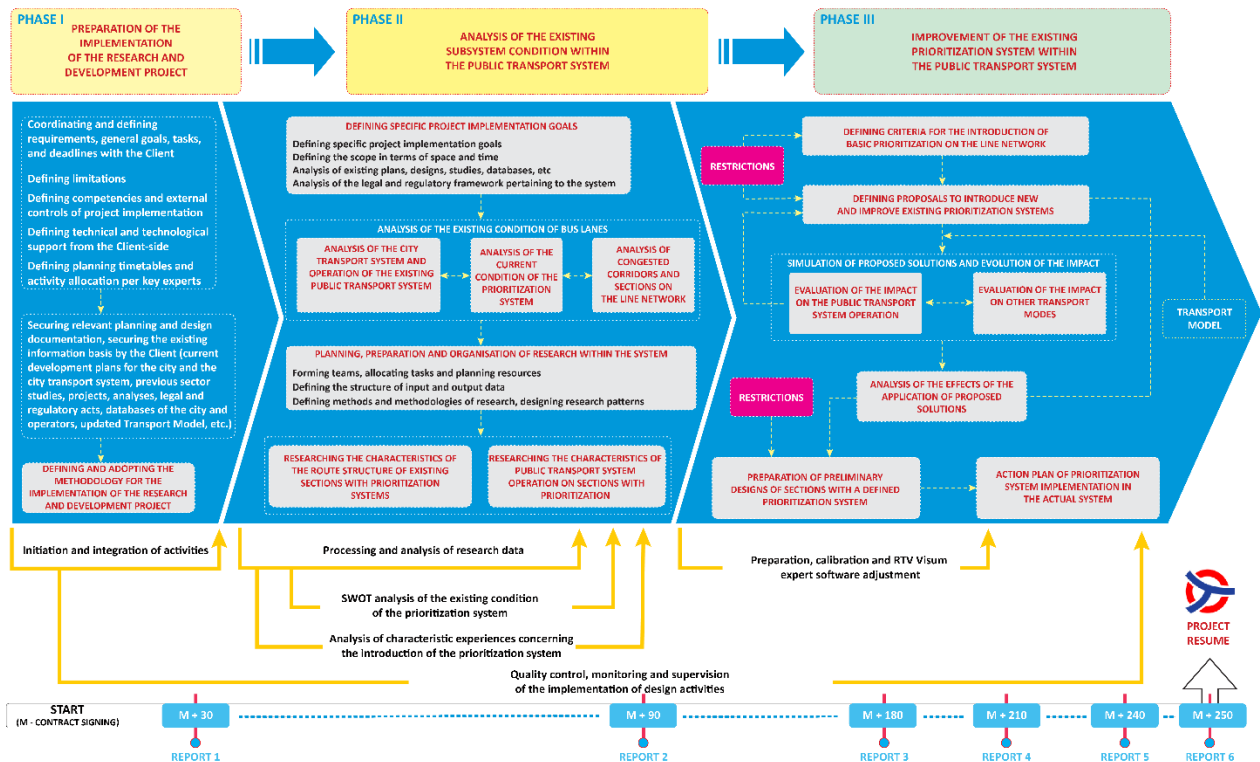


Image 1: The methodological process and flow of preparation of the research and development project

BOOKS 2 - ANALYSIS OF THE EXISTING CONDITION OF BUS LANES IN BELGRADE

According to the Client's Terms of Reference the subject of the analysis and research was also the research of the basic dynamic elements of the system's operation on sections with an existing prioritization system (the number of vehicles in operation, speeds, frequencies, common intervals, estimated vehicle occupancy at characteristic times of day, accumulation of vehicles on the busiest sections and stops, etc.), research of disturbances in timetable realization on line routes (causes, micro-locations where the disturbances occur, etc.).

Bearing in mind the objective impossibility of conducting this research within the real public transport system in Belgrade (changes in the system's mode of operation, the impossibility of immediate contact with citizens-users due to need for social distancing, etc.), caused by events from the preceding period (the COVID-19 pandemic, state of emergency and measures of the government of the Republic of Serbia) the analyses were conducted through extensive research of up-to-date databases on the system operation in the preceding period (data bases from the vehicle management system), in a stable mode of operation and a representative period of time, for the month of December 2019.

Analysis of basic characteristics of the service area

This chapter provides the basic characteristics of the socioeconomic and demographic characteristics of the area needed to gain insight into the complexity of the network of public passenger transport lines.

Analysis of the network of public passenger transport lines

This chapter defines the network of lines, as the basis infrastructural and operational element of the system of public passenger transport in Belgrade as a whole and the characteristics of three interconnected and physically integrated networks of the following subsystems:

- the tram subsystem,
- the trolleybus subsystem,
- the bus subsystem,

From the viewpoint of the number of subsystems within the total system, it is noticeable that the participation of subsystems with electric traction is predominant. However, in actuality the bus subsystem is predominant in the system structure, regardless of whether the static characteristics of the network or dynamic characteristics of the lines are taken into consideration.

This chapter contains data on basic operation results, production efficiency and utilization observed for each subsystem of the public transport system.

Operation results for the existing mode of operation for the bus system are shown for the characteristic workday, Wednesday, December 4th, 2019. The official Traffic Operation Report of the BusPlus system was used to calculate the parameters.

It is important to note that during the preparation of this report the trolleybus subsystem has been operating in a significantly altered regime and that, in order to objectively view the characteristics of the trolleybus subsystem, apart from its condition at this time, the cross-section of time before the current

interference occurred, i.e. March 2019 will also be analyzed. The only e-bus line (EKO1) was also analyzed within the trolleybus subsystem.

Basic operation results, production efficiency and utilization are provided for the tram subsystem according to lines for the existing (altered) and stable mode of operation. The cross-section used was January-February 2020 as well as a cross-section before the reconstruction started, i.e. May 2018.

Line network prioritization analysis

This chapter analyzes the current condition of the bus lane system in all streets and sections where there is a bus lane for public transport vehicles, taking into consideration the number of lanes, whether a bicycle lane exists in that part of the street, the automobile and taxi parking regime and technology, as well as which line and public passenger transport subsystem it belongs to. This chapter also includes an analysis of the marking methods, mode of operation, method of monitoring and control, as well as an analysis of the geometric elements of the network.

The analysis of the public transport on sections with bus lanes was prepared based on the planned timetable (for December 4th, 2019 – winter timetable). The analysis was prepared for all road sections with separate bus lanes, separately for each direction.

This chapter includes the SWOT analysis of the existing bus lanes in the network of public transport system lines. The primary goal of the SWOT analysis was gaining a clear and objective insight into the condition of the existing bus lane network and obtaining reliable input data for the design of the future public transport vehicle prioritization system.

Bus lanes exist in 30 streets in Belgrade. The total length of the sections where there are bus lanes for public transport vehicles (including the length of intersections) is 48,8 km, 34,5 km of which are has an all-day mode of use, i.e. from 00:00 to 24:00, while 14,3 km only operates during peak hours, i.e. from 07:00 to 09:00 and 14:00 to 18:00. The table shows that the tram subsystem uses 15,2 km of bus lanes, the trolleybus subsystem 4,0 km, while the bus subsystem uses the entire capacity of exclusive lanes: 48,8 km.

Analysis of case studies regarding the introduction of bus lanes and separate independent routes of the public transport system world-wide.

This chapter describes the different experiences concerning institutional organisations, bus lane design, bus lane utilization and compliance control for vehicles of the public passenger transport system in 11 cities in Europe, America, Asia and Australia. The analyzed cities were Vienna, Zagreb, Barcelona, Amsterdam, London, Paris, Los Angeles, New York, San Francisco, Seoul and Sydney.

Analysis of bottlenecks, congested corridors, and sections on the network of lines

This chapter describes the macro and micro analysis of bottlenecks in the bus, tram, and trolleybus subsystems of the public transport system. Within the micro-analysis, the average value of the realized interval on the line, the standard deviation of the realized interval on the line and the coefficient of variation at the characteristic stops on the network line of the public urban and suburban passenger transport system are presented.

The analysis also includes a calculation of speed, so that it was necessary to correct the provided driving times between stops in order to obtain the most precise data possible. The system registers the arrival, i.e. departure of the vehicle from the stop when the vehicle enters or exists the stop zone which is 20 meters in diameter. For this reason, 6 seconds were added to every driving time before it was used for further analysis.

BOOK 3 - DEFINING CRITERIA AND THE PROPOSED EXPANSION OF BUS LANES IN BELGRADE

Defining criteria for the introduction of bus lanes and separate independent line routes

This chapter is an analysis of the experiences and recommendations for defining criteria for the introduction of bus lanes. A specific methodology was defined for the selection of section of the network of lines where this kind of public transport system prioritization is viable. The methodology consists of multiple phases and in accordance with that two groups of evaluation criteria are used: basic and additional criteria. The basic criteria pertain strictly to the public transport system, i.e. the dynamic elements of the lines. Additional criteria include relative comparisons between the public transport system and individual transport (automobile) and the criteria indicating level of service for all vehicles in traffic.

Table 1: Criteria for the evaluation of bus lanes in Belgrade

Criterion	Values indicating the viability of separating routes of the public transport system
BASIC CRITERIA	
Vehicle frequency	- Greater than 20 vehicles/h
Transport speed	- Lower than 10 km/h
ADDITIONAL CRITERIA	
Passenger flow	- Greater than 800 passengers/h.
Time loss in intersections	- Service level at intersections higher than „C“
Vehicle flow/capacity ratio	- Service level no lower than „D“

The first step is to perform the primary analysis of potential sections (spacing of stops) in the network of public passenger transport lines where there is a need to introduce a certain kind of prioritization. Two basic criteria are used to select the group of potential sections: vehicle frequency and transport speed. The output group is comprised of all the sections that meet the conditions concerning the minimal departure frequency (20 vehicles/h) and the limit values of traffic speed parameters. Then, a check is made to establish whether the selected sections already have some form of prioritization concerning

the separation of routes of the public transport system. If this is the case, the methodology prescribes a detailed analysis of the operation of the public transport system with suggested re-engineering measures. The necessary input data in this phase are existing limitations and a reliable informational basis.

For sections meeting the basic criteria, where there is no prioritization regarding the separation of routes of public transport, a calculation of additional criteria values is performed. Firstly, it is established whether the passenger volume on the section is greater than the limit value (800 passengers/h). Then, all sections meeting this prerequisite are checked for service levels for vehicles in traffic and at intersections. If the service level on the section is less than „D“ it is considered that the section is not suitable for the prioritization of public transport vehicles since in that case the service level for other vehicles would further deteriorate. The service level in intersections criterion is used to eliminate sections where disturbances and difficulties in the public transport operation are not a consequence of the lack of lane capacity but rather the mode of operation in intersections. If the level of service, expressed as time loss of vehicles in the intersection, is greater than „C“, such sections are considered suitable for the introduction of bus lanes or other models for the separation of public passenger transport line routes. The output from this step are the sections which also meet the additional criteria. In the next step, the geometric profile on the selected sections is analyzed. The basic criterion is the number of traffic lanes per direction, according to which there should be at least two lanes each so that one can be converted into a bus lane. The second criterion is the possibility of road widening through appropriate construction in order to increase the number of lanes. If the required geometric profile is present, the introduction of adequate physical priority for vehicles of public transport is proposed. Otherwise, the next step is to consider changes in the mode of operation. Some of the possible changes include the introduction of a public transport road, change to a one-way road, etc. If such interventions are also impossible, changing the route of the public passenger transport line is proposed.

After the proposed measures are implemented, the methodology prescribes permanent monitoring and control of the system operation and the analysis of the effects of the applied measures. If the effects of the applied measures are positive there is no need for further analyses and interventions. In the event that the effects are poorer than planned, it is necessary to conduct a detailed analysis of the operation of the public transport systems with proposed re-engineering measures.

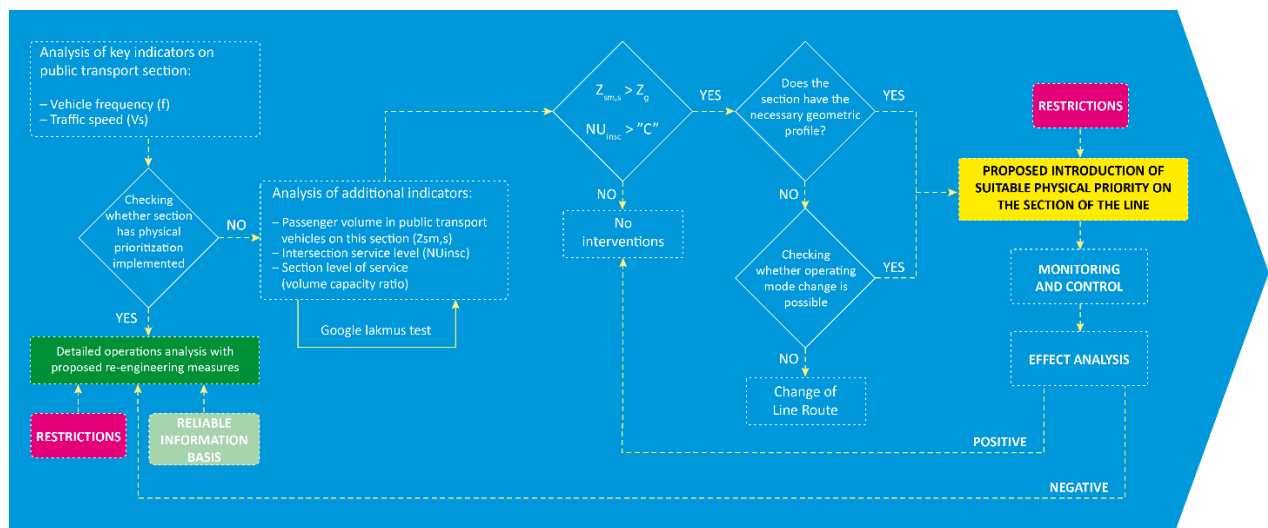


Image 2. The methodology for the selection of sections where the introduction of physical prioritization for public transport is feasible

Proposed sections of the road network where bus lanes can be introduced

This chapter shows the streets and sections where introducing bus lanes for public transport vehicles is proposed. All proposed expansions of the bus lanes in Belgrade, together with an improvement in public transport and the measures provided in the Sustainable Urban Mobility Plan will result in a reduction of automobile use and maintenance of the high participation of public transport in the modal distribution.

Table 2. Streets and sections with proposed changes and interventions

No.	Street	Section	Proposed operation mode intervention
1.	Kralja Milana, Terazije, Kolarčeva	From Slavija to Trg Republike	Only open for public transport vehicles, cyclists, residents and pedestrians.
2.	Resavska	From Bulevar kralja Aleksandra to Nemanjina	Only open to public transport vehicles and residents.
3.	Dečanska	From Bulevar Despota Stefana to the Terazije tunnel	Bus lane for public transport vehicles in a newly constructed lane.
4.	Brankova	Brankov most stop	Extend the “Brankov most” stop in the direction towards New Belgrade and mark a pedestrian/cyclist path.
5.	Ruzveltova, Mije Kovačevića	From Omladinski stadion to Bulevar kralja Aleksandra	Bus lane for public transport vehicles (both directions).
6.	Bulevar kralja Aleksandra	From Kneza Miloša to Ruzveltova	Bus lane for public transport vehicles (both directions)
		From Cvetkova pijaca to Ustanička	Bus lane for public transport vehicles (both directions)
7.	Bulevar kralja Aleksandra	From Kneza Miloša to Ustanička	Light signals – tram prioritization
8.	Cara Dušana, Džordža Vašingtona, 27. marta, Kraljice Marije	Following completion of works – entire length	Bus lane for public transport vehicles (both directions).
9.	Dobračina	Entire length	Only open for public transport vehicles, residents and pedestrians.
10.	Plavi most	Direction towards Šumice	Allow public transport vehicles to continue moving forward from the right-turn lane.
11.	Vojislava Ilića	From Ustanička to Žička	Bus lane for public transport vehicles (both directions)– interrupted yellow line to Mis Irbijeve
12.	Kneza Miloša	Mostar interchange – Birčaninova	Bus lane for public transport vehicles in the morning peak hours towards the city (07:00-09:00), and in the afternoon peak hours towards Mostar (14:00-16:00).
13.	Karađorđeva, Savska	Faculty of Economy to Mostar	HoV lanes (from Mostar to Savski trg), it is necessary to consider prioritization in the design phase.

No.	Street	Section	Proposed operation mode intervention
14.	Highway	From the Zmaj interchange to the Lasta interchange	Promotion of HoV lanes (wherever possible) in both directions.
15.	Tabanovačka	Triše Kaclerovića to autokomanda	Change from one way traffic to both ways, for all vehicles.
16.	Bulevar oslobođenja	Lepenička – roundabout	Road widening and introducing a bus lane for public transport vehicles from Lepenička street to the roundabout.
17.	Vojvode Stepe	From autokomanda to Save Maškovića	Changes in traffic and light signal operating modes.
18.	Crnotravska, Neznanog junaka	From Bahtijara Vagabzade to the roundabout	Three bus lanes with changeable signalling (stops with special extensions outside the main traffic flow)
19.	Save Maškovića	Bulevar oslobođenja – Vojvode Stepe	Road widening necessary, two lanes in the direction towards Vojvode Stepe.
20.	Radnička	Radnička Strugarska intersection	Separate the left turn from Radnička into Strugarska.
21.	Kirovljeva	Požeška to Visoka	Introducing a bus lane for public transport vehicles along the entire length of Kirovljeva street.
22.	Požeška – Kirovljeva intersection	Direction from Požeška towards Kirovljeva	Middle left-turn lane only for public transport.
23.	Požeška	From Kirovljeva to the tram overpass	Bus lane for public transport vehicles
24.	Blagoja Parovića	From Požeška to Kneza Višeslava	Stops in separate niches.
25.	Trgovačka	Intersection of Trgovačka towards Ace Jaksimovića	Left turn from the middle lane for public transport vehicles. Enable a connection from this lane to the bus stop in Ace Jaksimovića, by use of bus lane.
26.	Pilota Mihaila Petrovića	From Marička to Kneza Višeslava	(stops with special extensions outside the main traffic flow).
27.	Patrijarha Joanikija	From Pilota Mihaila Petrovića to the Vidikovac terminus	Stops in separate niches.
28.	Jurija Gagarina	From Gandijeva to Ada Bridge	HoV lanes (both directions).
29.	Bulevar Mihajla Pupina, Bulevar Nikole Tesle	Intersection of Bulevar Mihajla Pupina and Bulevar Nikole Tesle	Traffic sign reading: “Do not block the intersection”.
30.	Bulevar Mihajla Pupina, Milentija Popovića	Intersection of Bulevar Mihajla Pupina and Milentija Popovića	Traffic sign reading: “Do not block the intersection”.

No.	Street	Section	Proposed operation mode intervention
31.	Ada Bridge	Ada Bridge – Tošin bunar	Promotion of HoV lanes (wherever possible) in both directions.

Legend: Bus lane in the tram lane

In the existing conditions the length of bus lanes is 48,8 kilometres in both directions, and with the proposed new bus lanes the total length will be 74,105 kilometres in both directions. 25,305 kilometres of new bus lanes are proposed as well as the implementation of 43,5 kilometres of HoV lanes. HoV lanes are used by public transport vehicles, taxi vehicles, vehicles carrying at least two people and emergency vehicles.

Proposed geometrical elements and traffic signalling for defining bus lanes in the street network

This chapter provides conceptual design solutions for the bus lanes intended to be used by public transport vehicles, taxi vehicles, and vehicles carrying at least two people.

The following image shows the proposed marking of bus lanes for public transport vehicles and taxis. The proposal refers to the uninterrupted yellow line in the intersection approach zone. If there is a right turn, vehicles should be able to change lanes for the right turn 50m away from the intersection. The right turn will be marked by an interrupted white line 1+1 m as well as an uninterrupted yellow line. If there is no possibility to implement the 50 m distance in the field, it should be implemented at the greatest distance possible.

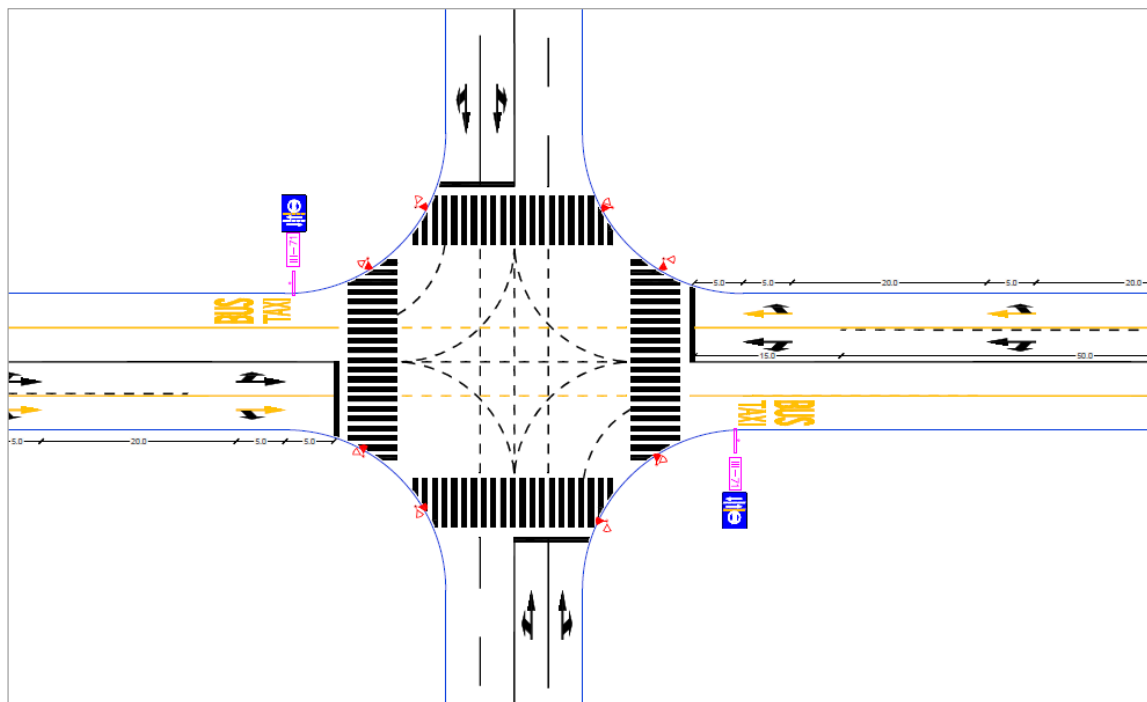


Image 3: An example of markings for public transport vehicle lanes in the intersection zone

The following images show the traffic sign and pictogram signalling bus lanes for vehicles carrying a minimum of two people.



Image 4: Proposed traffic sign for lanes for public transport vehicles, taxi vehicles and vehicles carrying a minimum of two people



Image 5: Proposed pictogram signalling lanes for vehicles carrying a minimum of two people

BOOK 4 - SIMULATION OF PROPOSED SOLUTIONS

Within this chapter we have provided a detailed description of the simulations performed, according to streets and sections. The simulation represents a process of modelling an actual event through simulation, although the event never took place. The simulation and description were performed using the model in the software package PTV VISUM, which is one of the world's leading planning tools.

Simulation of proposed solutions and impact assessment within the existing transport model of the city of Belgrade

In order to show the impact the proposed intervention would have on the current conditions, the existing transport model of Belgrade (TMB) was used. The TMB was created in 2015 and in order to implement this project and obtain the most precise results possible, it was necessary to adjust the existing version of the TMB to the actual conditions in the field, before modelling the proposed interventions.

As was previously mentioned, the existing version of the TMB is based on data from 2015, when the degree of motorization and number of automobile journeys were lower than today. For this reason, the number of automobile journeys in the model was raised by 20%.

Service level analyses were performed for the current and proposed conditions, as well as comparisons of volume and capacity (Volume Capacity Ratio PrT). The service level was marked A to F where A represents the highest service level corresponding to the conditions of free flow and F is the service level corresponding to forced flow.

Introducing a bus lane on a road leads to the reduction of its capacity so the next image shows the difference in the Volume Capacity Ratio compared to the existing condition (without introducing the proposed bus lanes).

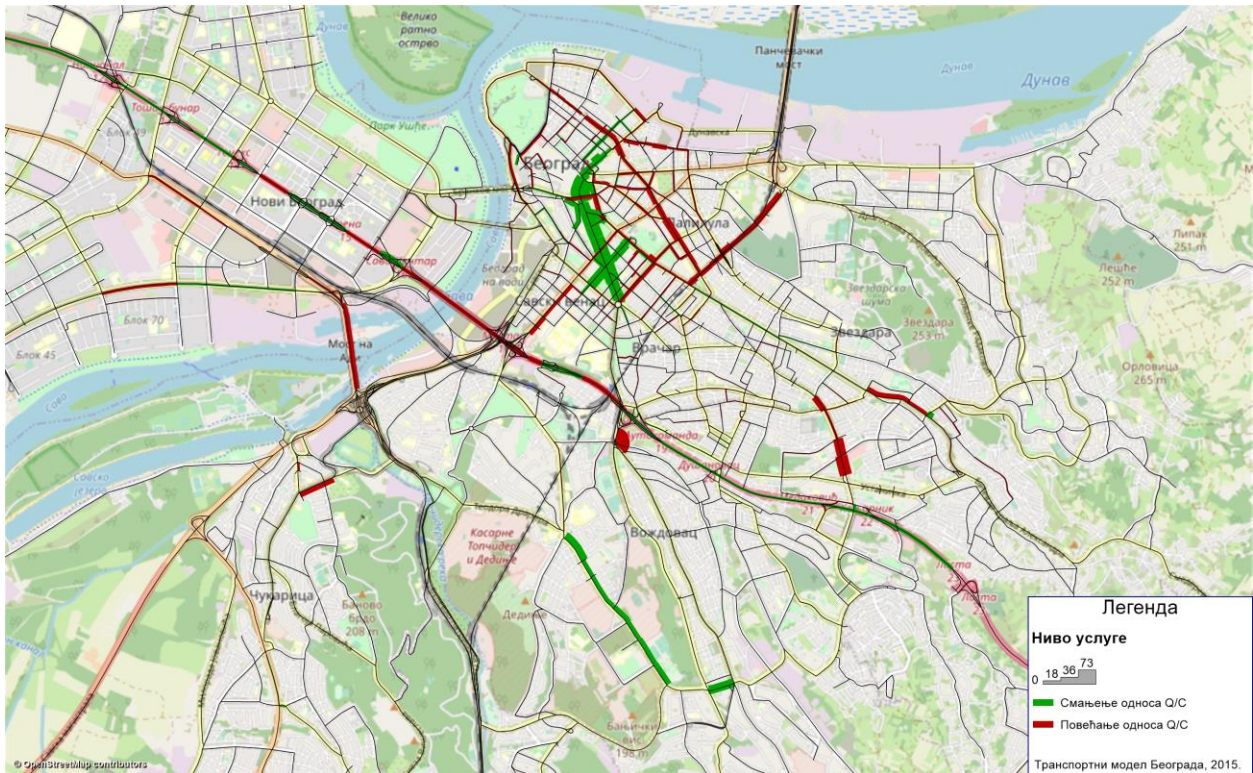


Image 6. Difference between the existing and proposed conditions

Analysis of the effect of the application of the proposed solutions

The development of modern transport system is essential to focus towards achieving a positive impact on the overall urban environment, which should aim at creating a city that is pleasant to the citizens and visitors stay, tourists and others. An innovative way of urban planning and urban transport systems sustainably meet primarily the needs of the people is the Sustainable Urban Mobility Plan (SUMP).

The City of Belgrade has adopted the project of the Sustainable Urban Mobility Plan in 2020. One of the main goals of this plan is to maintain a high share of public transport in the modal share in Belgrade. The goal is to keep the current 50% of public transport.

General effects on the project

Within this chapter, an overview of the average occupancy of passenger cars and the average occupancy of vehicles of all subsystems of public transport is given. The average filled vehicle of the bus and trolleybus subsystem transports the same number of passengers as 24 passenger cars, and one vehicle of the tram transport subsystem changes almost 20 passenger cars.

Effects of the project on public transport

It has been shown that the key problems and causes affecting the efficiency and quality of public transport in Belgrade are a consequence of the interaction of the system with its environment, and mostly external in nature. They permanently present primarily through chronic congestion in certain parts of the network, which in turn results in loss of operational speed and production of unnecessary

time loss on certain sections in the system's line network. Likewise, these external causes negatively impact the quality of the transport service, efficiency, productivity and attractiveness of the system, and so also its competitiveness compared to other passenger transport modes (primarily the automobile).

By applying a methodology that was specially designed to fit the needs of this project, and with a previously completed systemic analysis of the operation of the public transport system in Belgrade and an in-depth analysis of existing prioritization systems in the line network, with a focus on bottlenecks, as well as congested corridors and sections in the line network, we have proposed improvements to the prioritization system for public passenger transport vehicles (bus lanes and separate independent routes). The methodological steps presented as part of this project, together with the results of the research, comprise a specific and unique methodology specially developed to fit the needs of the public transport system in Belgrade.

In the process of prioritization system re-engineering, exact criteria were used to answer the question of whether public transport vehicles should be prioritized on a certain section, and primarily whether bus lanes and independent routes should be introduced.

Apart from this, a simulation of the impact the introduction of bus lanes would have on other dynamic traffic was executed in the Belgrade transport model (Chapter 10). However this resource suffers from deficiencies that made it impossible to quantify the simulation effects on the public transport system. These deficiencies mostly show themselves in the given (fixed) values for dynamic public transport network elements (speed, capacity, etc.).

However, with consistent application of the proposed solutions within this project the expected effects on the public transport system in Belgrade are as follows:

- Improvement in system operation on critical sections (traffic flow increase);
- Increased transport service quality through increased regularity, accuracy and reliability of the realization of planned timetables;
- Increased system efficiency primarily in terms of transport speed and time;
- Lower time-losses for passengers and operators
- Maintaining a high participation of the public transport system in the modal distribution ;
- Positive trend of increase in the number of transported passengers and income from core business (ticket income)
- Reduction of operating costs for the operator (primarily through energy saving by the reduction of time spent in "neutral" mode);
- Mitigation of the consequences of a complex traffic situation through the redistribution of mode of transport participation, i.e. the transition of resident mobility from passenger cars to the public transport system;
- Increased system energy efficiency;
- Increased ecological suitability through a reduction in emissions;

- Increased attractiveness and competitiveness of the system compared to other transport modes (primarily the automobile);
- Reduced infrastructure investment by means of re-purposing certain existing sections of the street network into bus lanes;
- Application of proven innovative solutions to increase flow for public transport and automobiles carrying two or more passengers (HoV 2+ lanes - High-occupancy vehicle lanes);
- Resolving long-term chronic difficulties in the line network (primarily the bus subsystem);
- Adopting the general postulates of European transport policy which takes as its basis the principle of efficient mobility with a limited use of automobiles;
- Explicit and concrete position of the city of Belgrade that mobility technology is above all relevant and current politics.

Apart from the above mentioned expected effects on the public transport system, it is expected that the proposed solutions will contribute to better operation of flexible passenger transport (taxi), as well as contribute to achieving a part of the social goals (horizontal and vertical equality for all citizens). The proposed resolutions are a tool to achieve the goals of sustainable development and quality of life in Belgrade. They also represent the first step in creating conditions for the public transport system to become and remain the key service and backbone of all mobility services. Following this project's implementation it is realistic to expect a mitigation of the trend of increasing motorization in Belgrade and of its effects on the modal distribution in the city's transport system.

With the goal of achieving these effects, it is necessary to particularly stress the following:

- Applying the proposed solutions which were obtained as part of this project through the use of a systemic approach will produce a significant improvement in public transport system operation;
- The results that can be achieved through a partial application of the project can lead to an instant improvement;
- With the goal of efficient implementation of the proposed solutions it is necessary to urgently define the jurisdiction of the city's professional authorities in terms of the distribution of authority in planning, design, implementation, coordination and operation of prioritization in the public transport system (primarily the Secretariat for Transport and Secretariat for Public Transport);
- It is necessary to continuously monitor the effects of the implemented measures and their influence on the city transport system's operation, and perform any micro-adjustments necessary based on the results of such monitoring;
- To ensure an explicit quantification of solutions, it is necessary to pay particular attention to public transport vehicle prioritization (sections and intersections) modelling in future versions of the Belgrade Transport Model and remove one of the key deficiencies in the existing Transport Model.

In planning the development of the Belgrade transport system in the future it is necessary to ensure the conditions for prioritizing the public transport system over other transport modes in the city network. It is also necessary to provide conditions for the development of a high level of interconnection of all elements in the city transport system by use of contemporary IoT (Internet of Things) technologies and

the development and implementation of adaptive prioritization systems within the city transport system based on real-time management.

Effects of the project on other dynamic traffic

This chapter shows the effects of bus lanes on increased flow and capacity by street and street section, and gives the flow/capacity ratio in existing conditions, projected conditions, as well as the difference between the two.

Definition of bus lane operation mode

The analysis of the existing bus lanes retained the existing mode of functioning, the all-day operation (00-24h) and the operation in peak hours (07-09 and 14-18h).

The bus lane system is established with the same parameters throughout the network. The operation mode for bus lanes is defined by vertical and horizontal signalling. Bus lanes in tram lanes are separated by tramline separators where they are not separated vertically. Operating mode limits for bus lane use are 24 hours 7 days a week, based on counting results and daily irregularities throughout the system during the day.

An exception is made for bus lanes in Kneza Miloša Street where bus lane use follows changes in the alternating use of lanes. The alternating use of lanes light signalization should be completed with signals for the alternating use of bus lanes.

Bus lanes can only be used by public transport vehicles, taxis and emergency vehicles. Stopping and parking is not permitted in the bus lanes. It is not permitted to stop delivery vehicles in bus lanes.

Control and Monitoring

The bus lane system will function well if it is accompanied by sound monitoring and control measures. Control that bus lanes are not used by unauthorized vehicles will be performed in several ways:

- Control by authorities (police, communal police, inspections...),
- Fixed cameras set up to control bus lane use,
- Traffic surveillance cameras on the territory of the city of Belgrade placed by the Ministry of Internal Affairs of the Republic of Serbia,
- Public transport vehicle cameras
- "Hawkeye" system.

For efficient control and monitoring, a system involving all relevant authorities must be established.

Defining dynamic of realization in the field

This study provides the possible realization dynamic based on an understanding of the realistic possibilities and interventions that need to be done in preparation. Implementing the bus lane system

and reserved corridors will depend upon the dynamic of work on the reconstruction and construction of streets in Belgrade.

To ensure successful implementation of this project the cooperation of the city's Secretariats for Transport and Public Transport is essential. It is also necessary to coordinate the activities of city services which are investors in the reconstruction or construction of streets in Belgrade (The City Investment Secretariat, Belgrade Land Development Agency) as well as investors of the major reconstructions in Belgrade (Belgrade Waterfront, Metro and Train Public Company, etc.).

According to the realization dynamics in the first year, streets have been selected which do not require large physical interventions and where it is sufficient to complete traffic signalization designs (horizontal and vertical), based on the instructions and examples provided in this study.

The second year of implementation deals with streets requiring greater interventions and additional research and design. We recommend that preparation activities begin in the first year and realization is performed in the second year.

And finally, the most complex cases are planned for the third year, which includes the preparation of the technical documentation over the course of the first two years, followed by implementation. The following table proposes the realization dynamic of streets and street sections.

Table 3: The dynamic of realization in the field

No	Street	Section	Suggested intervention regime	2021	2022	2023	Note
1.	Kralja Milana, Terazije, Kolarčeva	From Slavija to Trg Republike	Only open for public transport vehicles, cyclists, residents and pedestrians.	✓	✓	✓	Realization in phases, design exists
2.	Resavska	from Bulevar kralja Aleksandra to Nemanjina	Only open to public transport vehicles and residents.		✓		Prepare traffic signalization design
3.	Dečanska	From Bulevar Despota Stefana to Terazije tunnel	Bus lane for public transport vehicles in a newly constructed Bus lane.	✓	✓		Prepare micro-simulation and reconstruction design for the street and intersection
4.	Brankova	Brankov most bus stop	Extend the "Brankov most" stop in the direction towards New Belgrade and mark a pedestrian/cyclist path.	✓	✓		Prepare civil design and traffic signalization design
5.	Ruzveltova, Mije Kovačevića	From Bulevar kralja Aleksandra to Omladinskog stadiona	Bus lane for public transport vehicles (both directions).	✓			Prepare traffic signalization design
6.	Bulevar kralja Aleksandra	From Kneza Miloša to Ruzveltova	Bus lane for public transport vehicles (both directions)		✓		Prepare traffic signalization design and correct light signalization design
		From Cvetkova pijaca to Ustanička	Bus lane for public transport vehicles (both directions)			✓	After reconstruction is competed

No	Street	Section	Suggested intervention regime	2021	2022	2023	Note
7.	Bulevar kralja Aleksandra	From Kneza Miloša to Ustanička	Light signalization – tram prioritization	✓			In accordance with the implementation of the project
8.	Cara Dušana, Džordža Vašingtona, 27. marta, Kraljice Marije	Following completion of works – entire length	Bus lane(both directions).	✓	✓		Following completion of reconstruction works, prepare traffic signalization design changes
9.	Dobračina	Entire lenth	Only open for public transport vehicles, residents and pedestrians.		✓		Prepare traffic signalization design
10.	Plavi most	Towards Šumice	Allow public transport vehicles to continue moving forward from the right-turn lane.	✓			Prepare civil design of the intersection reconstruction and traffic signalization.
11.	Vojislava Ilića	From Ustanička to Žička	Bus lane for public transport vehicles (both directions)– interrupted yellow line to Mis Irbijeve	✓			Prepare traffic signalization design
12.	Kneza Miloša	Mostar – Birčaninova intersection	Bus lane for public transport vehicles in the morning peak hours towards the city (07:00-09:00), and in the afternoon peak hours towards Mostar (14:00-16:00		✓	✓	The dynamic is dependent on the street reconstruction, Prepare traffic signalization design and the correction of the light signalization design.
13.	Karađorđeva, Savska	Faculty of Economy to Mostar	HoV lanes (from Mostar to Savski trg), it is necessary to consider prioritization in the design phase.		✓	✓	Prepare traffic signalization design, amendment of the law, control and campaigns
14.	Highway	From the Zmaj interchange to the Lasta interchange	Promotion of HoV lanes (wherever possible) in both directions.		✓	✓	Traffic signalization design, amendment of the law, control, campaigns
15.	Tabanovačka	From Triše Kaclerovića to Autokomanda	Change from one way traffic to both ways, for all vehicles.		✓	✓	Resolve property relations Complete civil design for the reconstruction and traffic signalization design
16.	Bulevar Oslobođenja	Lepenička–roundabout	Road widening and introducing a Bus lane for public transport vehicles from Lepenička street to the roundabout.		✓		Prepare civil design and traffic signalization design
17.	Vojvode Stepe	From autokomanda to Save Maškovića	Changes in traffic and light signal operating modes.		✓	✓	It is necessary to complete a separate study and design.

No	Street	Section	Suggested intervention regime	2021	2022	2023	Note
18.	Crnotravska, Neznamog junaka	From Bahtijara Vagabzade to roundabout	Three Bus lanes with changeable signalling (stops with special extensions outside the main flow of traffic)			✓	In accordance with the implementation of the project
19.	Save Maškovića	Bulevar oslobođenja – Vojvode Stepe	Road widening necessary, two lanes in the direction towards Vojvode Stepe.		✓		Implementation by Belgrade Land Development Agency. Check realization dynamics and solution
20.	Radnička	Radnička - Strugarska intersection	Separate the left turn from Radnička into Strugarska. .		✓	✓	Prepare civil design and traffic signalization design
21.	Kirovljeva	Požeška to Visoka	Introducing a bus lane for public transport vehicles along the entire length of Kirovljeva street.	✓			Prepare traffic signalization design
22.	Požeška – Kirovljeva intersection	Direction from Požeška towards Kirovljeva	Middle left-turn lane only for public transport	✓			Prepare traffic signalization design
23.	Požeška	From Kirovljeva to the tram overpass	Bus lane for public transport vehicles.	✓			Prepare traffic signalization design
24.	Blagoja Parovića	From Požeška to Kneza Višeslava	Stops in separate niches.		✓	✓	Prepare civil design and traffic signalization design
25.	Trgovačka	Trgovačka intersection towards Ace Joksimovića	Left turn from the middle lane for public transport vehicles. Enable a connection from this lane to the bus stop in Ace Joksimovića, by use of bus lane.		✓		Prepare civil design and traffic signalization design
26.	Pilota Mihaila Petrovića	From Marička to Kneza Višeslava	(stops with special extensions outside the main flow of traffic).	✓	✓		Prepare design of horizontal, vertical and light signalization
27.	Patrijarha Joanikija	From Pilota Mihaila Petrovića to Vidikovac Од Пилота Михаила Петровића до Vidikovac terminus	Stops in separate niches.		✓	✓	Prepare civil design and traffic signalization design
28.	Jurija Gagarina	From Gandijeva to Ada Bridge	HoV lanes (both directions).		✓		Traffic signalization design, amendment of the law, control, campaigns
29.	Bulevar Mihajla Pupina, Milentija Popovića	Intersection of Mihajla Pupina and Milentija Popovića	Traffic signal marking: “Do not block the intersection”.	✓			Traffic signalization design and construction of pedestrian underpass

No	Street	Section	Suggested intervention regime	2021	2022	2023	Note
30.	Mihajla Pupina, Buleva Nikole Tesle	Intersection of Mihajla Pupina and Bulevar Nikole Tesle	Traffic signal marking: "Do not block the intersection".	✓			Traffic signalization design
31.	Ada Bridge	Ada Bridge – Tošin Bunar	Promotion of HoV lanes (wherever possible) in both directions		✓	✓	Traffic signalization design, amendment of the law, control, campaigns

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