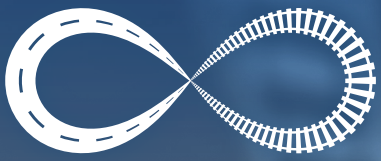

CETRA 2018

5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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ZAGREB METRO PLANS – CURRENT ISSUES AND FUTURE DEVELOPMENT

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Abstract

Today, due to the long-term neglect of Zagreb's public transport infrastructure, existing public transport systems (tram and bus) and the independent city-suburban railway system do not meet the required levels of service. The main problems of the city's image regarding transport, in addition to the constant inflation in the number of passenger cars, are non-compliant time-tables of various public transportation systems and arbitrary price-versus realizable quality of service. At the same time, plans for the introduction of the new rail system in Zagreb's public transport have been announced for decades. Numerous proposals have been made on various track route variants, which usually predict the introduction of underground lines and links to the existing rail network (narrow gauge tram or standard gauge railway tracks). In addition, the new city Master Plan re-envisages a metro line (or "Light Rail Underground") in the city centre. This paper gives a comparison of design and exploitation parameters of urban rail concepts proposed for Zagreb in the last 20 years. The aim of the analysis was to determine whether any of these concepts meet today's requirements or weather the changes in the city's space and transportation needs are so vast that the future development of the public rail system needs to be planned from scratch.

Keywords: City of Zagreb, rail public transport, urban network development, concept variants

1 Introduction

Transport in the City of Zagreb relies on a combination of city-managed mass and individual transportation. Public mass transport (PT) is composed of 19 inner-city tram lines and 120 bus routes, which are managed by Zagrebački električni tramvaj (Zagreb Electric Tram). HŽ putnički prijevoz (HŽ Passenger Transport) manages the parallel Zagreb Commuter Rail system [1]. These systems transport around 300 million passengers per year [2]. Unfortunately, due to due to the long-term neglect of Zagreb's public transport infrastructure, these existing PT systems do not meet the required levels of service. The main problems of the City's image regarding transport, in addition to the constant inflation in the number of passenger cars, are non-compliant timetables of PT systems and arbitrary price-versus realizable quality of service. These are the main reasons that existing systems are used on a daily basis by only a third of the cities' population.
Every city that strives to be competitive in an intense process of economic globalization must emphasize its flexibility in satisfying its resident's transportation needs. In the same sense, PT must be able to follow and even encourage the development of city areas it serves and to meet possible future travel patterns. This can only be achieved through the creation of a modern, efficient, and viable PT network, which is extending across the entire urban area

and imposing itself as a high-value alternative to the use of personal vehicles. As electric rail systems meet all of the criteria and objectives of sustainable urban development, they have always been recognized as the future of environmentally sustainable and high quality PT in Zagreb. Different plans for the expansion of PT rail systems in Zagreb's have been announced for decades. Numerous proposals have been made on various track route variants, which usually predict the introduction of underground lines and links to the existing rail network (narrow gauge tram or standard gauge railway tracks). In addition, the new city Master Plan re-envisages a metro line (or "Light Rail Underground") in the city centre. In this paper, five urban rail concepts proposed for Zagreb in the last 20 years are described. Spatial restrictions (natural and man-made), geological characteristics of the area, and other issues concerning the growth and development of the City, and, consequently, its PT network, are also described.

2 Current issues

Zagreb's development was influenced by the topography of the region. The historic settlement's location at the foot of Mt. Medvednica, and the spatial restrictions that discouraged its development towards the south (rail line at the south part of the historic settlement and the River Sava, Fig. 1.) resulted in the predominantly longitudinal development of the City in the E-W direction. Today, the River Sava divides the City into two main parts: older settlements (built after the WWII around historic Lower and Upper City) on the north side, and New Zagreb, the residential area that was built in the last 40 years on the south side. Major traffic barriers extend mostly in E-W direction [3]. Furthermore, central area of the Lower City is protected for its historical architecture (Fig. 1.): the introduction of new structures is strictly controlled, and adapting existing historical functions and content to contemporary needs can be accepted only if the intervention in historical structures is minimal [4].
In terms of hydrogeological conditions, northern part the City is situated on mostly unstable slopes of Mt. Medvednica, while the Lower Town and the lowlands of New Zagreb are situated in Sava basin. In this area, the topsoil is comprised of sand, clayey sand and sandy clay. Below this topsoil, whose thickness ranges from 0 to about 7 meters, is the aquifer, comprised mostly of gravel and sand. The average thickness of this horizon in City's area ranges from 10 to 15 meters. Subsoil layers below the aquifer are comprised of gravelly clays and silty clays. The water face is about 2 to 5 meters below the terrain surface, and tectonic activity is accompanied by faults in the NE-SW direction, as shown in Fig. 1. [5 – 7].
Within its current limits, the City of Zagreb consists of 70 settlements with the total area of about 641 km^2 [8]. According to the latest population census, there are 790.017 residents living within the City's administrative limits, and 87 % of them are occupying the Zagreb settlement Fig. 2. shows population density in different city settlements [8], and existing PT network (bus, tram, and rail).
Apart from the historical city centre, the development of urban areas is not followed by the concurrent development of the rail PT network, as shown in Fig. 2. Today, PT users in most of these areas rely solely on the bus system. Within City limits, bus transport is organized in 146 lines (1400 km long) with annual 65k transported passengers per network km. Most bus terminals are situated at the edges of the central city area and act as main tram system suppliers. Comprised of 60 km narrow gauge double-tracks, tram network is a PT backbone with annually transported 940k passengers per network km. Transport is organized in 19 tram lines (210 km long) with tram daytime headway between 6 and 11 minutes. There are 256 tram stops on an average distance of 468 m [9]. About 50 % of the tracks share lanes with car traffic, so tram's operating speed depends greatly on the road traffic density. In addition, trams do not have priority right at a signalized intersection. Because of that, average operating tram speed is only 12 km/h [10]. Suburban and urban railway PT, which takes place on 58 km of tracks (240 km long lines), is served by 17 stations. Operating train speed of 40 km/h is very satisfactory [9]. Following the modification of the tariff model and the abolition

of the Zagreb City subventions to HŽ Passenger Transport from 2012 onwards, there has been a significant fall in the annual number of passengers transported by rail, from 210k to today's 35k passengers per network km.

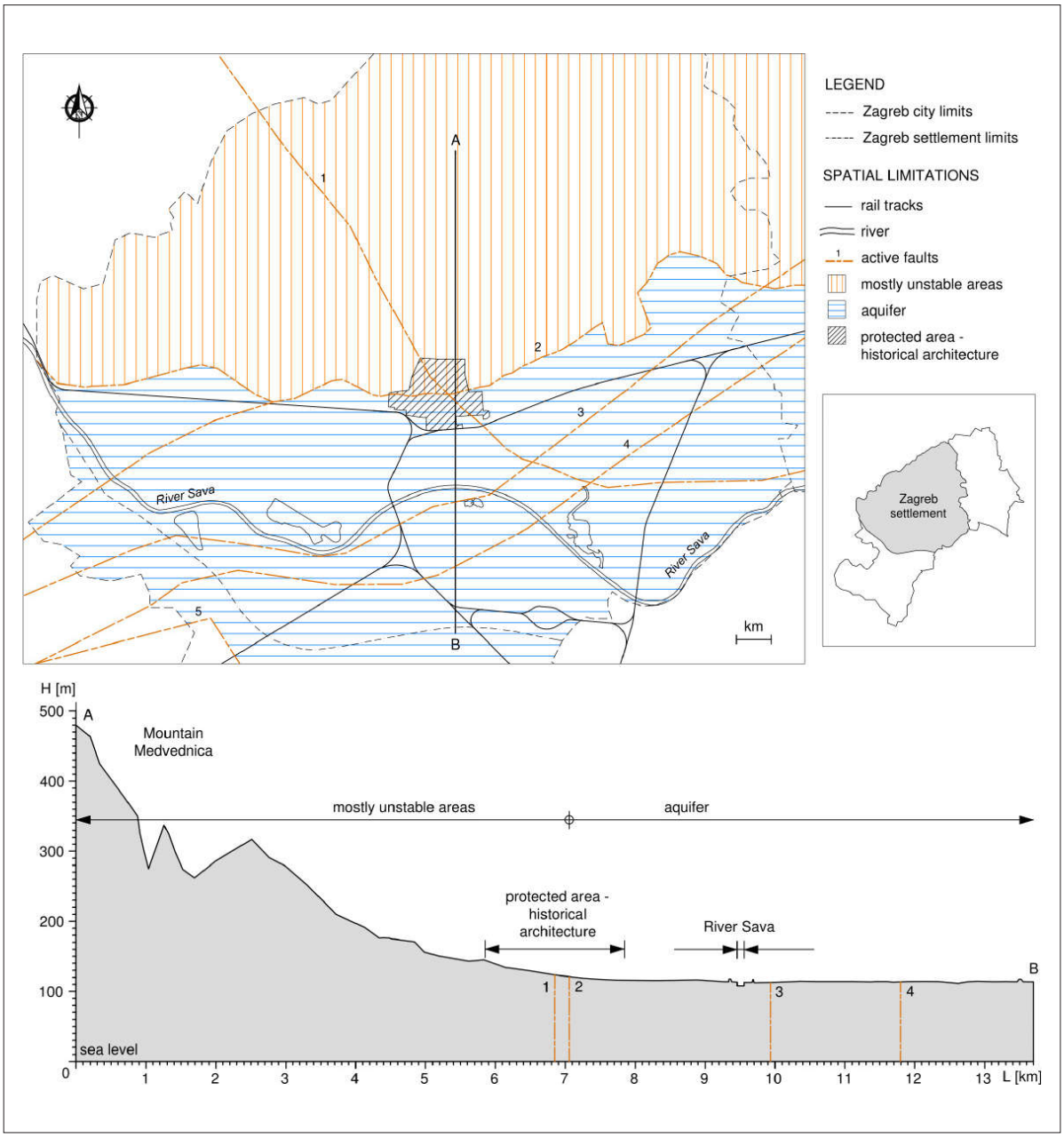

Figure 1 The City of Zagreb – spatial characteristics and limitations

Despite the above-mentioned problems, analysis of the statistical data given in [2] showed that today PT is used by 35 % of City population. However, the share of passenger cars (33 %) and public bus users (11 %) significantly exceeds the share of the electric rail transport users – tram (23 %) and train (1 %). One of the frequently mentioned possible solutions for improving the rail PT in Zagreb is the construction of the underground rail system. This is considered the only variant that can still be incorporated into the City structure due to the high degree of urbanization and motorization. In general, the basic goals in planning a sustainable PT network expansion are reflected in increased system economic efficiency, environmental protection, increased safety of all traffic participants, and improved availability of PT in newly-developed city zones (which need to be systematically and periodically re-identified on the basis of an increase of potential PT users).

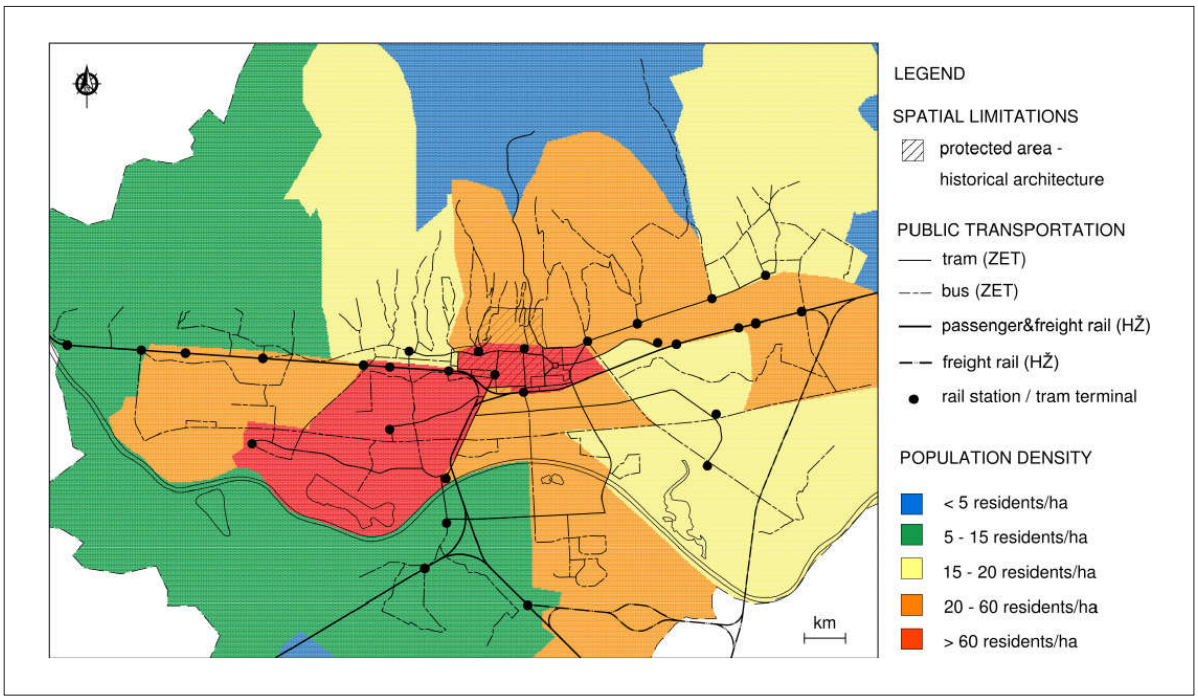

Figure 2 Existing public transportation network and population density (in 2011.)

3 Proposed solutions

According to [6], first technical-founded reasons for the construction of underground rail (metro) system in the City of Zagreb can be found in professional papers from the 1970's. In this section, an overview of five variant solutions of new PT rail system for the City is given. These variants differ in the direction and length of the tracks, access to the existing PT rail system and the location of the track (underground or surface), as shown in Fig. 3. and Table 1.

The first variant (VAR1) [6] consists of an underground ring around Lower Town and below the northern avenue in New Zagreb, and four underground tracks that radiate from the City's central square in the historic area to the E and W part of the City. The proposed solution also includes a link between the centre of the City and the satellite town Velika Gorica. 70 % of the track is located underground, at a depth of 15 to 20 meters below the surface, in the layers of clay. Overground sections include bridges across the Sava River and the track to the south. Proposed excavation methods are NATM or application of TBM for tube excavation and Top-down method for stops.

The second variant (VAR2) [11], consists of surface and underground sections of the tram network radiating from the City's centre to the residential areas on the E, W and S. The track is located underground just in the historic centre and in the densely built area of THE Lower City. The proposed method of construction of the underground stops includes excavation from the surface with the use of concrete diaphragms, while the tunnel tube sections are to be excavated by TBM in the layer of clay. The design of a double track in a single bored tunnel is proposed.

The third variant (VAR3) [12] foresees the construction of a ring that would bypass the protected centre of the City, and run beneath the planned southern avenue in New Zagreb. Four underground tracks radiate from the City's central square to the E, W, S and N. Largest part of the planned track is located underground. Overground sections include three bridges across the Sava River. The construction of twin-bored tunnel (two parallel tubes, one for each track) at an 11-meter distance is proposed. The proposed construction method for underground stops is C&C, while tunnel tubes are to be excavated by TBM.

The fourth variant (VAR4) [13], which is integrated into the current City plans, envisages the upgrade of the existing tram network. In this variant, only the planned tram tracks passing through the historic area in the centre of the Lower Town (14 % of the planned tracks) are under ground.
The fifth variant (VAR5) [1, 14], consists of a ring south of the rail line on the south border of Lower Town, under the River Sava and beneath the planned southern avenue in Novi Zagreb. The construction of twin-bored tunnel (two parallel tubes, one for each track) is suggested. The proposed excavation methods are NATM or TBM for the tunnel tubes and Top-down method for underground stations.

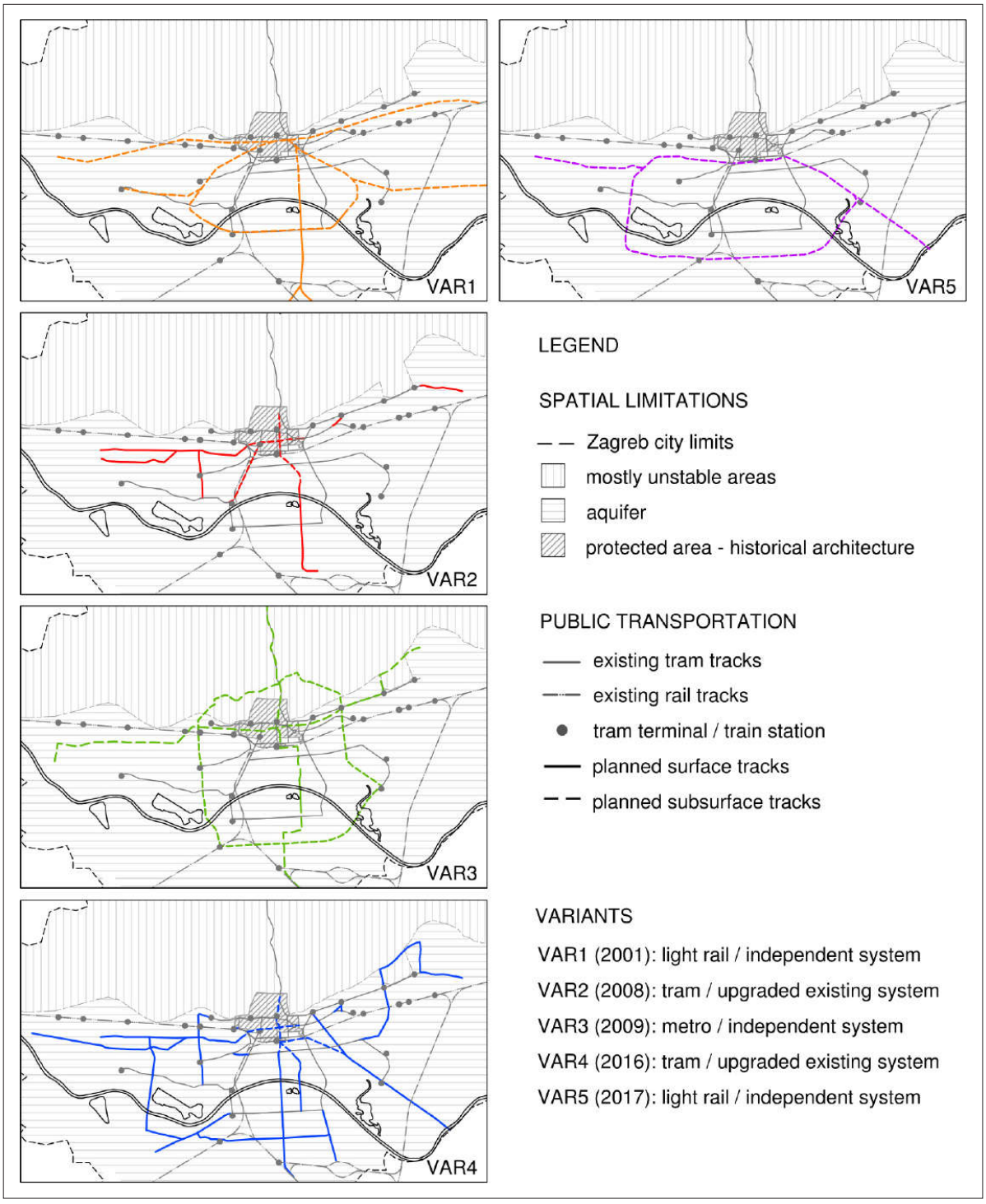

Figure 3 Analysed variants [1, 6, 11-14]

Other design characteristics of aforementioned variants are shown in Table 1. The direct connection between the existing and planned PT network is proposed only in variants VAR2 and VAR4, through the upgrade of the existing tram network. Solutions for the new Light Rail and Metro lines imply separate rail systems with vertical passenger links to existing bus and tram network exclusively in station (terminal) zones.

4 Discussion

When planning new PT corridors, the desired operational speed and traveling time must be secured. To determine the travelling speed, the average stop distance was calculated based on the predicted number of stops. Then the average traveling speed was approximated based on the estimated vehicle acceleration and deceleration and station intervals (Table 1.). It was concluded that the estimated speed of the tram system (VAR2 and VAR4) is the lowest, but it is satisfactory given the usual tram travel speed in a separate corridor. Only the metro variant VAR3 did not achieve the balance between design speed and station distances. A larger number of stops could attract more passengers, but it significantly increases networks construction and operating costs, making it ineffective in the long run.
Even thou only partial proposals given in VAR2 took hold in the City's plans, it should be noted that the possible impact of rail PT was assessed by City's administrators during the preparation of VAR4. Considered measures were: (1) extension of existing tram tracks, (2) construction of a new rail link from the City's centre to Zagreb Airport, (3) improving headway on existing lines, and (4) introduction of a new mass transit system (metro). The analysis has shown that only headway improvements deserve to be further discussed, for the following reasons. Most of the demand for rail transport comes from suburban areas, which is why Cities' support to line extensions is declared inappropriate. At the same time, demands for new rail lines within the City area are low, since they duplicate with tram lines that provide a wider coverage of the entire city. In addition, projections show that the number of Airport passengers will not justify the construction of a rail link for another 30 years. As for the metro system, foreign experiences show that sustainable system requires a demand of at least 10k passengers per hour, which is far more than the demand on any PT corridor in Zagreb [15]. Because of these findings, proposed metro line in VAR5 is connecting the suburban areas of the city (where the population growth greatly intensified in the last decade) with south part of Lower Town in the locations of the main railway and bus stations, providing vertical passenger links to existing rail, bus, and tram network.

Table 1 Variant design and operational characteristics

Variant	1	2	3	4	5
System	Light Rail	Tram	Metro	Tram	Metro
Track gauge [mm]	1435	1000	1435	1000	1435
Total track length [km]	55	26	58	64	35
Underground track [%]	70	31	98	14	100
Shared network*	NO	YES	NO	YES	NO
Design speed [km/h]	50	30	45	30	50
Min curve radius [m]	300	20	100	20	180
Max grade [mm/m]	35	70	40	70	35
Number of stops	25	41	52	85	20
Stop distance** [km]	2,2	0,6	1,1	0,8	1,7
Travelling speed** [km/h]	34	22	27	23	34

** NO = independent new network with passenger links to existing PT network only in station zones; YES = existing PT tram network extension; ** calculated average values*

5 Conclusions

The assessment of the proposals for the metro system as a fully independent new PT system in Zagreb showed that the demand is insufficient to justify such large investment. Light rail (tram) systems are still the most suitable for Zagreb [15]. Due to very good surface PT coverage, especially in the W-E direction, metro construction can be considered unnecessary. For the sustainable link between City's E and W suburban areas and its centre, and the interconnection of the N and S areas, separate double tram tracks should be planned as parts of the new major city corridors [3]. It is important to question the necessity of introduction of new underground tram routes in the historic area (because of a number of problems that may arise in their planning and construction: from traffic organization to securing historic buildings during the excavation and construction), and to analyse in detail if proper organizational measures (right of way, limitation of car traffic in the narrow city centre, etc.) could provide the required efficiency of the surface tram system.
In spite of the conclusions reached at the City level, it should be emphasized that the existing rail network presents underestimated resource that must overcome the problems of irregular station intervals and inadequate stop facilities. As Zagreb railway node represents the central core of the railway network in the Republic of Croatia linked to the TEN-T network, its development to high-quality passenger rail network should not be considered separately from other PT systems. Today, rail corridor occupies much of the high valued urban areas, and its routes, for now, provide the optimum opportunity for the development of the PT network. In addition, its planned modernization is too expensive to allow its future competition with other PT systems. For sustainable development of the PT system in Zagreb, all existing and planned systems must complement each other by reorganization of service provision at least through the integration of tickets and timetables.

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