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TRAFFIC AND TECHNOLOGICAL ASSUMPTIONS FOR THE METRO IN THE CITY OF SPLIT

ABSTRACT

Rationalization of the traffic systems in major cities, which includes Split, is possible at present only by providing a more diverse and higher quality supply of public urban transport.

In Split the situation in public urban transport shows that it does not meet its basic function. Only partial or transitional solutions are offered. All this contributes to the delay in making the decision which is the only possible one in the city of Split regarding its size and the level of motorization.

The solution of the public urban transport lies in the introduction of the metro system through phase construction. Each phase represents in fact the construction of one line. Due to the complexity of the construction of the underground section (tunnel construction in the centre of the City) the first phase is the most demanding one regarding construction works, with two metro lines intersecting (the need to build two-level stations) and therefore this section is the most complex and the most expensive part in the network of the metro line system.

KEY WORDS

public transport, HOVs, metro

1. INTRODUCTION

The topic has been chosen with the intention of improving the existing public urban traffic system, since all the previous attempts to improve and enhance the road traffic management by implementation of information and communication technologies in traffic have not given the expected results, nor has the existing public urban transport been capable of satisfying the increasing problems.

This problem has been getting more complex by the growing level of motorization and construction of the Split-Zagreb highway, which requires greater efficiency and accuracy, road vehicle traffic flows, and the transport of the arriving passengers from other transport modes – land, air and maritime traffic.

It will not be possible to realize well the acceptance of a greater number of vehicles and passengers in the city of Split with the existing traffic infrastructure if the existing vehicle and passenger traffic flow systems are not improved, with the expansion of the existing traffic network by the construction of new roads in order to accommodate a growing number of passenger transport between the individual city zones and the central city and settlements of the Split catchment area.

Therefore, new solutions are being looked for today, whose efficiency will be able to satisfy various needs and at the same time be the right answer to solve the city problems. It is obvious that for the solution the entire existing and available infrastructure will be used and new more efficient transport means will be planned, with higher capacity (since the solution is focused on the public urban transport), i. e. mass transport means.

2. EXISTING SYSTEM OF STREET NETWORK

The central parts of the urban areas in the city of Split are burdened by intensive traffic flows of pedestrians, public urban transport vehicles and motor vehicles. The traffic demands in the city, and especially in its central part have been increased by the method of usage and attractiveness of the space which additionally burden the traffic network system of that area.

The street network system in the city of Split has been stipulated by the physical position of the city and

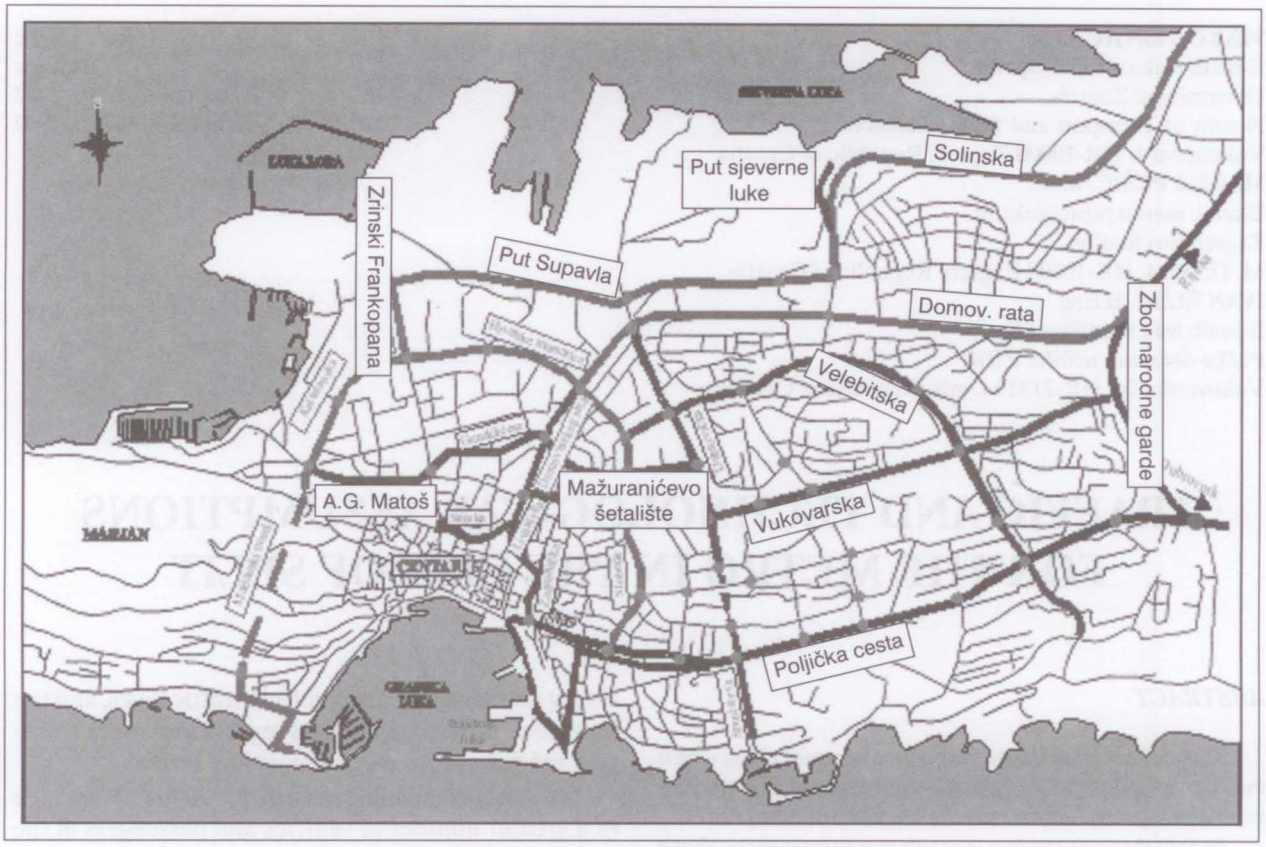

Figure 1 - Categorized streets in Split [1]

the characteristic construction of a Mediterranean type with the dominating historical core of the city. Therefore, road traffic is organized in very complex conditions and is of moderate spatial possibilities, i. e. without possibility to expand the urban traffic network, which is therefore geometrically irregular and of a narrow profile. Consequently, it does not satisfy all the conditions in road categorization, safety of vehicle and pedestrian flows, which have been stipulated by the level of motorization which is to a certain extent satisfied only by state and county roads in the city of Split, Figure 1.

The existing method of using certain streets and spaces, lack of uniformity in the distribution in the central parts of the city cause congestion of traffic flows in certain traffic areas in the centre as well as in the surrounding streets and squares. This is the consequence of the road infrastructure gradually adapting by construction and needs of the city development (by the construction of residential, industrial zones, of commercial, sport, cultural and other facilities). The majority of the main city streets has been constructed with four lanes, apart from the main incoming roads which have six lanes, and these are Ulica Domovinskog rata and Poljička cesta. The traffic on the primary city streets has been regulated as two-way traffic, except for the Mažuranićevo šetalište and part of Vukovarska ulica where the traffic flows one way.

In this part of the city special place is occupied by the city port, which represents regarding its significance the most attractive point on the eastern coast of the Adriatic Sea and attracts a large number of origin-destination and transit transport of passengers and goods. The eastern part of the city port Split accommodates passenger traffic terminals (road, rail, air and sea), and the western part accommodates hotels, tourist and business facilities. There is intensive maritime traffic in the aquatorium of the city port, both in public transport of passengers and road vehicles and in the individual sea traffic by smaller vessels.

The port area together with the central part of the city is connected to the urban, interurban and international transport of passengers by systems ranging from road, rail, air to sea transport, with individual transport present as well. Such provision of services in the traffic of passengers and vehicles at one location represents a unique traffic system.

3. PUBLIC URBAN TRANSPORT SYSTEM

Public urban transport in the city of Split consists basically of bus transport with densely distributed stops across the entire city area. The central part of the city is relatively well connected with other parts of

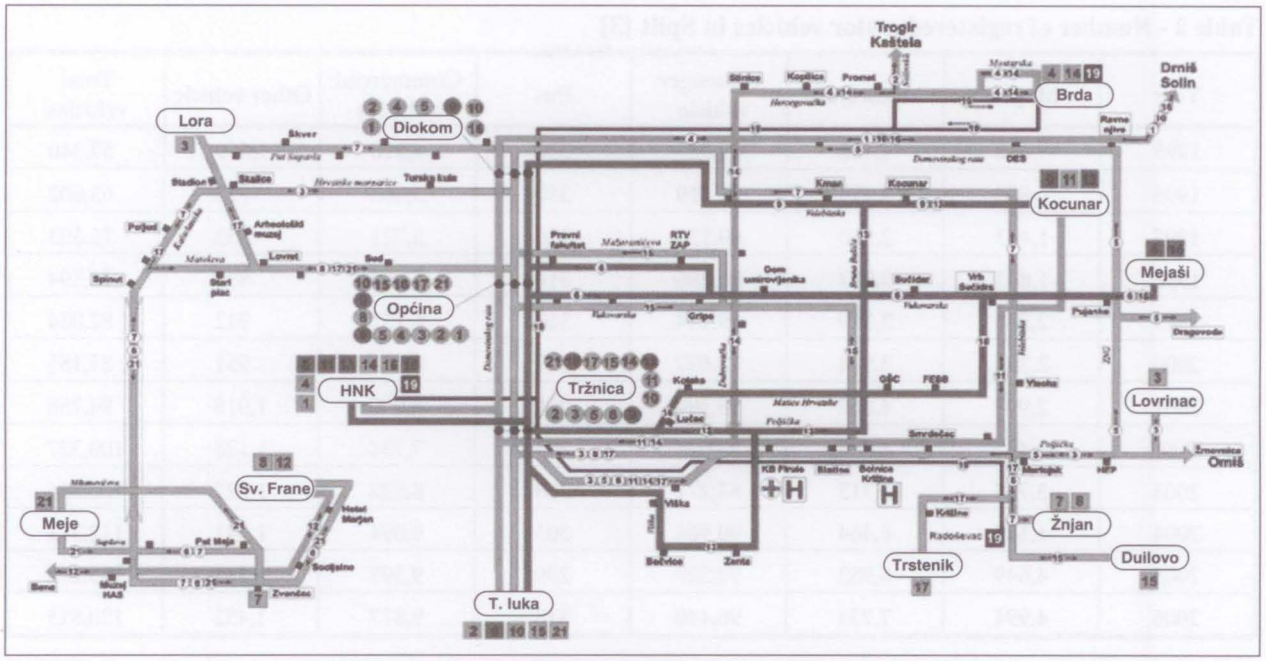

Figure 2 - Network of public urban transport lines [2]

Table 1 - Daily number of carried passengers by public transport (in thousands) with the estimate of the number of passenger trips in 2015

Carrier	1989	2006	1989/2006 %	2015
Railway transport	2,616	784	-299.7	3,425
Public urban transport	174,285	89,128	-195.5	194,285
Ferry	5,430	5,401	-100.5	1,203
Bus station	5,715	3,331	-171.6	96,330
Airport	2,545	1,095	-229.7	4,384
Total:	190,591	99,739	-191.1	212,927

the city, by lines with bus stops at the edges of pedestrian zones.

The bus line tracks pass along streets to the traffic ring around the city centre, tangentially touching the most burdened part of the city. Because of its physical form the public transport through the street network of the city of Split has been organized in the following way:

a) radially,
b) longitudinally, and
c) transversally.

Public urban passenger transport has been organized by conventional and articulated city buses, on line 21, which forms the line network that cover almost all the residential zones of the city, Figure 2.

In order to obtain a better picture of the usage of public transport in the city of Split, the number of carried passengers needs to be compared to the number of citizens of the city of Split. Thus, 180 passengers per citizen were carried annually by public urban transport in 2000. This illustrates a sharp decline of using public transport in Split, since in 1989 this ratio was 326 passengers per citizen annually. This was the year (previous years had also shown such trend) of high level of public transport demand in Split, which, when compared to other European cities where the average level of using public transport is between 80-110 passengers (trips) per citizen, was three times larger.

However, since there has been a fall in the trips made by public transport, i. e. the process of balancing transport with the more developed European countries has started, which eventually means shift of passengers to passenger car transport and serious disturbance of the trip relations, which goes in favour of individual transport.

Table 1 shows the condition of today's urban transport in Split which is burdened by a number of traffic problems. This condition is reflected first of all in the gap between the supply and the demand for transport services, disharmony between the needs and the possibilities of satisfying the traffic demands. Thus, the consequences are seen in the traffic jams in the morn-

Table 2 - Number of registered motor vehicles in Split [3]

Year	Moped	Motorcycle	Passenger vehicle	Bus	Commercial vehicles	Other vehicle	Total vehicles
1995	412	1,400	49,327	332	4,310	1,559	57,340
1996	870	2,173	54,419	350	5,066	724	63,602
1997	1,443	2,850	60,130	326	5,721	833	71,303
1998	1,843	3,083	64,296	314	5,967	891	76,394
1999	2,238	3,329	69,144	310	6,151	912	82,084
2000	2,321	3,504	73,697	297	6,411	951	87,181
2001	2,997	4,052	79,394	298	6,999	1,018	94,758
l2002	3,442	4,704	83,026	293	7,734	1,128	100,327
2003	3,795	5,713	87,271	308	8,522	1,227	106,836
2004	4,143	6,464	90,964	305	9,094	1,341	112,311
2005	4,649	6,983	92,529	299	9,397	1,385	115,242
2006	4,994	7,734	96,440	318	9,877	1,452	120,815

Table 3 - Number of whole-day trips within the Split catchment area

Year	Number of citizens	Factor 1991	Mobility of citizens	Factor 1991	Mass of trips	Factor 1991
1991	244,500	1.00	1.75	1.00	427,875	1.00
2001	252,523	1.03	1.90	1.96	479,794	1.12
2006	281,869	1.15	1.90	2.19	535,551	1.25

ing and afternoon traffic peak hours, with parallel relatively high, individual and social costs of traffic. All this is, naturally, accompanied by noise and air pollution, especially in the central part of the city, and some other unfavourable effects on the environmental quality. The main reason for such a condition is the accelerated growth of registered motor vehicles, i. e. extremely high level of motorization in the city of Split which amounts to 429 motor vehicles per 1000 inhabitants with slight increase of road network capacities (i. e. 342 passenger cars per 1000 inhabitants) and the area for parking spaces.

4. NUMBER OF REGISTERED MOTOR VEHICLES

Today's condition of urban traffic is burdened by many problems. Since in Croatia, including Split, there is no policy of control or discouraging of citizens from purchasing and using passenger cars that are more and more used recently in many European countries, the number of these vehicles is expected to continue to grow. This is indicated by the data on the number of passenger vehicles seen from Table 2.

5. NUMBER OF TRIPS

By increasing the social income, standard, shortening of the working hours and changes in the methods of earning and other things, a significant increase in the mobility of citizens is likely to be expected. The increase in the number of citizens and various activities of these citizens need to be added here, thus significantly increasing the total mass of trips in the city. The travel distance increases at the same time, as well as the travel time. Therefore, it is necessary to consider the introduction of new transport technologies for the transport of passengers in the city of Split.

In such conditions the role of adequate organization of public urban transport is increasing so that the citizens and visitors from a wider region would be able to reach their destinations in the shortest time possible and as comfortably as possible. From this viewpoint, it has been determined that the public urban traffic of Split does not correspond to the existing requirements and some new systems need to be introduced regarding satisfaction of the traffic demand.

For better illustration, including the significance of the weight of the problem which should be tackled with timely and adequate measures that need to in-

clude the still expected increase in the number of citizens and especially justified the expected increase in the mobility of citizens as expression of the development of the freedom of movement and general freedom. In case of setting such a principle, it is possible to calculate the number of possible daily trips presented in Figure 3.

These data show a more intensive growth in the total volume of trips compared to the growth in the number of citizens and their mobility. The basic problem that needs to be solved is how to provide so many trips with no harmful consequences for the urban structure and the environment.

Table 4 - Number of citizens of Split and its catchment area in the year 2001 [4]

Town	Number of citizens	Area [km^2]	Density [st/km^2]
Split	187,599	79.33	2364.79
Solin	18,784	18.37	1022.54
Kaštela	33,338	57.67	578.08
Trogir	12,612	39.10	322.81
Total:	252,333	194.47	1297.54
Podstrana	7,271	11.62	625.73
Dugi Rat	7,146	10.80	661.67
Omiš	15,109	266.20	56.26
Total	29,526	288.62	102.30
Overall:	281,864	483.09	583.47

When the data from 1989 and 2000 are related to each other using the model for the calculation of the passengers boarding the public urban transport means, on the one hand and passenger cars and commercial vehicles on the other hand, then we obtain the calculation about the boarding public transport in the city of Split, passenger and commercial vehicles, as presented in Table 5.

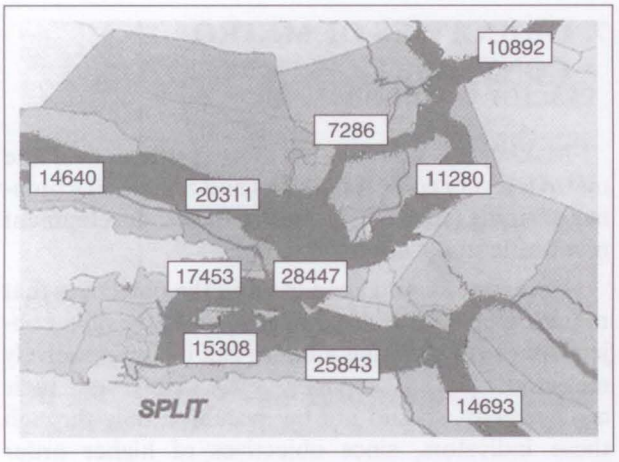

Figure 3 - Average daily traffic of motor vehicles along major city streets [5]

Table 5 - Number of passengers boarding transport means during 24 hours

Carrier	1989	2006	2015
Railway transport	3,715	1,098	4,864
Public urban transport	247,285	124,779	275,885
Ferry	7,711	7,561	1,708
Bus station	8,115	4,663	13,679
Airport	3,614	1,533	6,225
Total public transport	270,440	139,634	302,361
Passenger cars	72,157	270,032	408,027
Commercial vehicles	7,680	23,704	40,617
Total:	79,837	307,760	448,644
Overall:	350,277	447,394	856,671

According to this calculation the city of Split shows a need for 447,394 boardings in 2006, which is increasing daily (estimate for 2015 is 856,671 boardings) and requires a new transport system of higher capacity if very serious traffic problems are to be avoided.

It should be mentioned here, that bus transport network uses city streets, so that passenger cars, commercial vehicles, buses and other similar vehicles compete for the limited space on the streets which causes traffic congestion in many parts of the city (Figure 3). Such situation jeopardizes the relatively small density of the road network, which causes concentration of traffic on a limited number of main roads, including also the efficiency of bus i. e. public urban transport.

It is precisely because of these problems that it is very important to know the total capacities of the vehicles used in the transport along the streets, which could be used because of the increase in the transport demand, due to the increase in the number of citizens and the number of motor vehicles.

According to this estimate, in the year 2015, the city of Split would have 325,888 citizens with 162,648 registered motor vehicles (according to the IGH estimate in the year 2028 the city of Split would have 224,547 registered motor vehicles). These estimates confirm the thesis about the difficulty of the problem facing the city of Split, and which should be solved as soon as possible in order to avoid traffic congestion and standstill in the development of the city. The best way for this is to make a substantial improvement in public urban transport, i. e. by introducing a new system of higher capacity, comfort and speed.

Figure 4 - Pedestrian flows towards the centre of the City [1]

6. PEDESTRIAN FLOWS

Split is a Mediterranean city with favourable climate in which the citizens, apart from walking to work, spend their free time very often in the open. This is especially so in summer when a lot of tourists and citizens spend their time in the pedestrian zones, i. e. streets reserved for pedestrians, or at city beaches and other attractive locations such as visiting cultural and historical sights. Out of the total number of travel demands (depending on the season – whether winter or summer) the pedestrian traffic accounts for from 17.4% to 26% of traffic.

For the access to the strict city centre, as the dominant pedestrian zone in Split there are several pedestrian flows that connect wider regions and the strict city centre (Figure 4), and these are:

- *western access*, Matoševa and Plinarska ulica,
- *northern access*, Zrinsko-Frankopanska and Sukošanska ulica,
- *eastern access*, Mažuranićevo šetalište, Vukovarska and Tolstojeva ulica,
- *southern access*, Ulica kralja Zvonimira and Trumbićeva obala.

Apart from the mentioned access paths there are also two dominant pedestrian flows along the coast, and these are: Obala kneza Branimira and Obala kneza Domagoja.

The transversal profiles of the areas and the streets exclusively meant for the pedestrians, are adapted to the morphology and construction level of the space and are of very irregular form with the dimensions of some 1.5 to 6.0 and more metres. In the streets which accommodate traffic, the width of the pedestrian paths amount to 1.2 to 3.0 metres.

7. OBJECTIVES OF METRO CONSTRUCTION

Making the decision on the construction of the metro is a very complex process and related to a number of studies such as geological studies, development of a traffic study, discussions, etc.

Here, one should keep in mind the objectives that require special considerations. Some of the direct objectives of constructing a metro can be quantitatively measured (speed, capacity, etc.). However, their achievements should not be evaluated only through these indicators, since objectives of higher order dominate in the decision-making. Since specific objectives cannot be precisely quantified, their evalua-

tion is most often of secondary importance in determining the overall justification of the investments.

Objectives of highest order in the construction of a metro system in the majority of cases include:

- increase in the number of public urban transport users and greater citizens mobility;
- enabling a more uniform development of the city in the entire area;
- ensuring much better integral transport, as a good basis for the competition to passenger vehicles;
- ensuring greater attractiveness of public urban transport for the users of individual transport;
- ensuring higher reliability of transport services;
- influence the urban development by creating functionally organized, efficient and attractive urban forms, a base for the urban life of higher quality.

Diversity of objectives of the metro construction justification indicates the fact that a certain number of factors can very favourably reflect on the introduction of the system in certain cities. The most important of these factors is certainly the size of the city, its form and the construction density. These determine the number of trips on certain lines, or on the entire area of the city, as well as the justification of investing into the metro system.

The conditions of public and individual transport of a city can influence the decision-making. Narrow streets, traffic congestion, impossibility to ensure the priority for public urban transport of passengers, very often accelerate the decision on the construction of segregated lanes, i. e. metro.

Besides, each city (especially regarding big cities) should have a well considered traffic policy, coordinated planning and adequate system of financing traffic infrastructure facilities.

Semi-solutions or even improvements of the existing systems are of short-term character and they do not require high investments.

The construction of a metro would be a traffic solution for the city of Split, due to all the mentioned facts facing the city of Split, and especially in the expectation of substantially higher investments in road infrastructure (more expensive kilometre of road infrastructure construction) than the construction of metro.

8. PROPOSAL OF BASIC LINES SYSTEM

The construction of metro requires the highest initial investments, but has the lowest exploitation costs and the possibility of increase in capacities.

Metro stops are organized in intervals of catchment zones of ca. 900m – 1500m, and are located as a rule at locations of city squares, highest concentrations of public life and central living facilities, big residential zones, i. e. concentration of citizens, workplaces, sport facilities, parks, recreational spaces, traffic junctions and contacts with other means of public urban passenger transport and concentration of business blocks. Special significance is paid to the dispositions of the starting stations at suburban locations which accommodate big shopping and supply centres and big public parking lots for passenger cars.

Analyzing the overall needs of the city of Split and its citizens, the following metro lines are the most important:

Line 1 **basic route, leg I:**
Meje-Zvončac-Grad-Gripe-Sućidar-Neslanovac-Bilica-Meterize-Solin

basic route, leg II: Solin-Kaštela-Airport-Trogir.

Line 2 **basic route**: Kopilica-Supaval-Sutojica-Poljud-Dobri-Grad-Bačvice-Firule-Križine-Mertojak-Sučurac-Podstran

The metro lines are laid in shallow excavations to the depth of up to 10m (Figure 6), that is 15-20 m (Figure 7) in tunnel excavations, and more, depending on the hydrological and geological conditions. Tunnels are easier for tracking lines that are laid independently of the communal installations and the stability of the foundations of the existing construction. Lines of regional metro are designed in principle above ground, as well as the lines of city metro where possible. In city metro, the traffic operates on shorter relations and with higher frequency of 2 to 3 minutes headway with maximal efficiency of 45,000 pax/h in one direction, whereas in metropolitan (regional) metro the technical conditions are adapted to the need of longer relations and lower frequency.

Innovations move towards improvement of performances and the quality of public urban transport, speed and comfort for the reduction of exploitation and investment costs, great technology and construction advancements. Also, great technical and technological advancement in the metro construction have been achieved, and they significantly affect the price and the speed of construction.

9. CONCLUSION

The results of this work show that the development of traffic infrastructure and the passenger terminals was influenced by the increase in the number of passenger trips and number of vehicles. However, due to the limited space (since the city of Split is located on a peninsula), the existing areas cannot be used limitlessly for traffic purposes for the expansion of city street networks, but rather for other facilities necessary for the functioning and the development of the city.

Figure 5 - Proposal of metro system lines for the City of Split

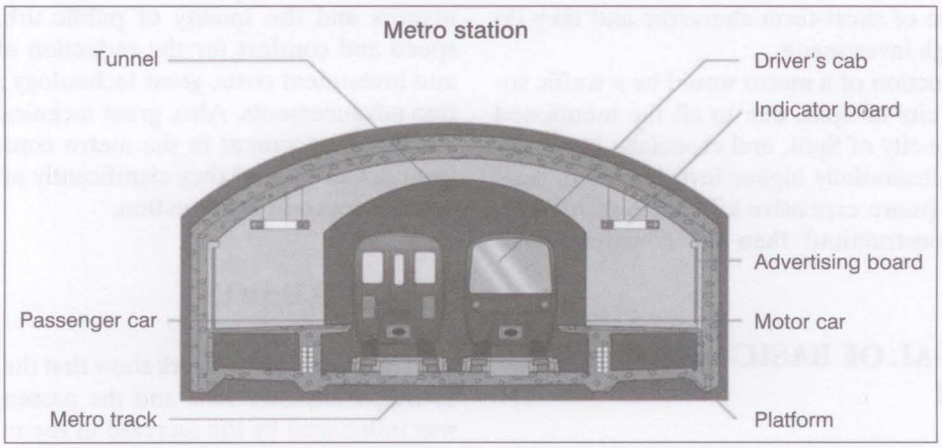

Figure 6 - Schematic presentation of the metro station in shallow tunnel

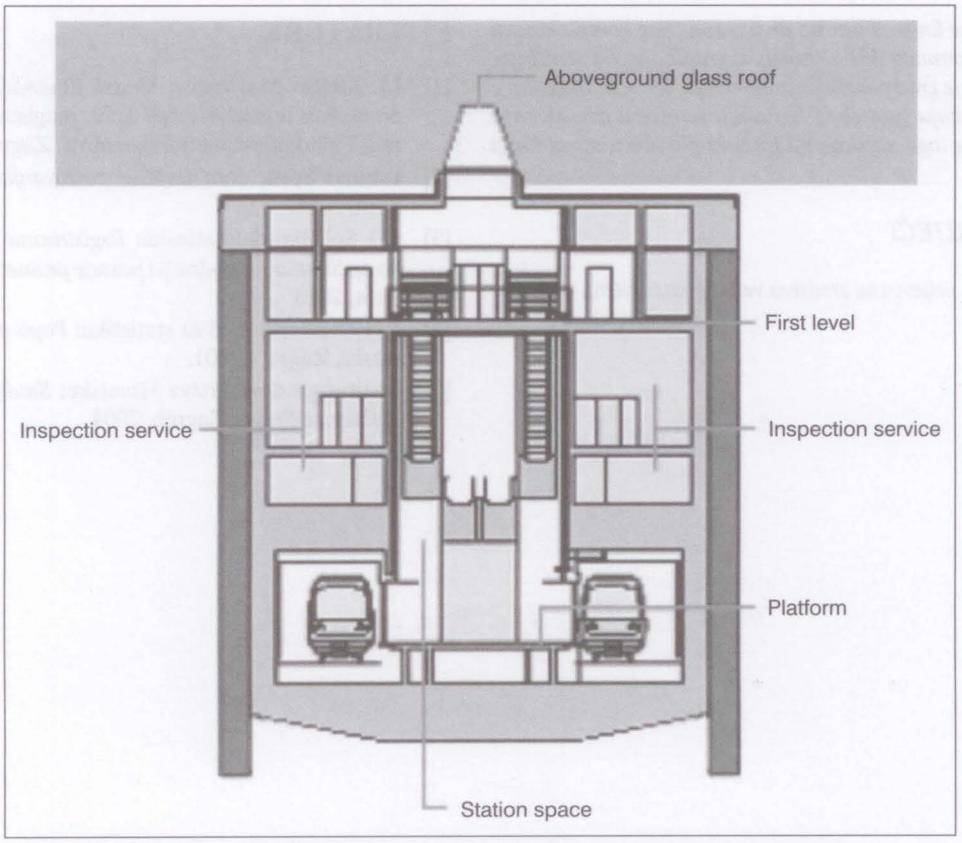

Figure 7 - Schematic presentation of station in deep-level tunnel

The increasing level of urbanization and the development of economy affect the increase of travel demands, which is reflected in the increase of passenger capacities, which cannot be satisfied by constant increase in the level of motorization, i. e. by increasing the number of motor vehicles and by constructing the traffic infrastructure, but by implementation of advanced technical and technological systems of greater capacity in public urban transport of passengers.

Since the existing structure of public urban transport of the city of Split cannot ensure fast overcoming of greater distances on the line relations of the travelling desires, it is necessary to select and define the most favourable new mode, which will enable faster and more rational urban and suburban public transport at the appropriate level of serviceability and phase implementation.

Since in the Split urban traffic system there is no mode of mass transport, it is necessary to start planning, designing and constructing a high capacity system such as metro, particularly due to the constant increase in the number of citizens, larger travelling distances (in time and space) and the increasing number of passenger vehicles whose great numbers are becoming a danger and a factor restricting development in the limited space of the city of Split.

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SAŽETAK

PROMETNO-TEHNOLOŠKE PRETPOSTAVKE ZA METRO U PODRUČJU GRADA SPLITA

Racionalizacija prometnog sustava u većim gradovima pa tako i u Splitu moguća je u današnje vrijeme jedino raznovrsnijom i kvalitetnijom prometnom ponudom javnog gradskog prijevoza. Uvođenjem više oblika javnog prijevoza u skladu s komparativnim prednostima pojedinog oblika, može se jamčiti veća pouzdanost i efikasnost javnog gradskog prijevoza.

U Splitu stanje javnog gradskog prijevoza pokazuje, da ne zadovoljava svoju osnovnu funkciju. Pri tome se nude polovična ili prijelazna rješenja. Sve to usporava donošenje odluke koja je jedina moguća u gradu Splitu s obzirom na njegovu veličinu i stupanj motorizacije.

Rješenje javnog gradskog prijevoza je u uvođenju metro sustava, kroz etapnu izgradnju. Svaka etapa predstavlja u biti

izgradnju jedne linije. S tim što prva etapa zbog kompleksnosti izgradnje podzemnog dijela (tunelska gradnja ispod središnjeg dijela Grada) je građevinski najzahtjevnija, jer se tu dvije linije metroa presijecaju (potrebna izgradnja stanice u dva nivoa) i upravo je zbog toga najsloženiji i najskuplji dio u mreži linija metro.

KLJUČNE RIJEČI

javni prijevoz, prijevozna sredstva velikog kapaciteta, metro

LITERATURE

[1] **Lj. Juričev-Martinčev**: *Modeli dinamičkog upravljanja prometom u gradskoj luci Split*, magistarski znanstveni rad, Fakultet prometnih znanosti, Zagreb, 2006.

[2] Promet Split, doo: *Izvješće poslovanja za 2005. god.*, Split, 2005.

[3] PU Splitsko-dalmatinska: *Registrirana motorna vozila po općinama na području postaje prometne policije Split*, Split, 2006

[4] RH Državni zavod za statistiku: *Popis stanovništva Hrvatske*, Zagreb, 2001.

[5] Institut građevinarstva Hrvatske: *Studija opravdanosti obilaznice Splita*, Zagreb, 2004.