

ANTUN STIPETIĆ, D.Sc.  
Fakultet prometnih znanosti  
Vukelićeva 4, 10000 Zagreb, Republika Hrvatska  
NENAD KLARIĆ, B.Eng.  
SLAVKO ŠERIĆ, B.Eng.  
Hrvatske željeznice  
Zlodrina poljana 20, 21000 Split

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## TRAFFIC AND TECHNOLOGICAL SOLUTION OF THE URBAN AND SUBURBAN RAILWAYS OF THE CITY OF SPLIT

### ABSTRACT

*In accordance with the advanced concepts of humanisation and rationalisation of traffic, an increasing number of activities is being undertaken in order to calm the traffic in the central parts of the cities and to increase it in the suburban districts. The development of transport means is accompanied by the need to redefine the segment of urban area due to greater mobility of the citizens. One of the efficient systems of organising traffic is the urban railway. The aim of the urban railway is to alleviate the burden on the urban and suburban traffic routes accommodating excessive road traffic and to provide rational integration into the system of urban public transit.*

*The traffic network in the Split-Kaštela area has been mainly constructed at times of very low traffic requirements, and today it cannot satisfy the increased traffic needs. Because of the impossibility to substantially increase the capacity of the urban roads, lack of parking space, and also due to environmental requirements, no increase in the share of the personal transport of passengers should be expected. In such conditions public transport of passengers can save the urban agglomeration from total traffic and environmental collapse.*

*The railways is precisely the mode of transport that should represent in the future the backbone of the public urban and suburban transport in the Split-Kaštela region.*

### KEY WORDS

*railway, Split-Kaštela area, public urban transport, mobility of citizens*

### 1. INTRODUCTION

Rail vehicles are strictly determined by the railway tracks, and therefore have priority over all the other transport modes. Considering from the aspect of going to and coming back from work, tourist sightseeing, citizens visiting shopping centres in the suburb, the railway has great advantages since it allows much shorter travelling times through the city. It is precisely for this reason that the railways needs to be considered as the subject of the city development. When congestion by road vehicles is considered, the lack of

public parking spaces, the harmful emissions, and its influence on the cultural heritage which is of invaluable significance for the city of Split, it may be concluded that the development of urban and suburban railway traffic in the city of Split and in its environment needs to be considered very seriously.

### 2. DEMOGRAPHIC AND ECONOMIC CHARACTERISTICS OF THE CITY OF SPLIT AND ITS ENVIRONMENT

The city of Split today has about 220,000 inhabitants, out of which more than 35 percent live in the catchment zone of the railway line. The town of Solin has approximately 30,000 inhabitants and about 40 percent gravitate to the railway route, whereas Kaštela has about 40,000 inhabitants, and over 50 percent gravitate to the railway line. The suburban towns of the Split-Kaštela region, Trogir and Podstrana have together over 40,000 inhabitants.

More than 60 percent of the industrial and commercial potential can be found in the railway line zone in Split, and near 75 percent in the town of Solin, and about 50 percent in Kaštela.

In planning the traffic demand in the Split-Kaštela region, it is necessary to analyse the population distribution and growth, and to estimate the number of jobs at the end of the planning phase (the year 2015), when substantial increase in the suburban population is expected (in Kaštela by 64 percent and in Solin by 116 percent).

In the specific circumstances of the social and economic development of this region (after the Croatian War of Independence), when the greater part of the economic subjects are passing through the restructuring process, it would not be realistic to expect any greater economic development prior to 2005. However, the forecast includes an increase in the number of jobs in catering activities in the town of Split, mainly

in the private sector, whereas this number is expected to fall in the industrial zones of Solin and Kaštela.

### 3. CURRENT CONDITION IN PUBLIC URBAN AND SUBURBAN TRAFFIC

Before the Croatian War of Independence, the monopoly on passenger transport in urban and suburban traffic belonged to the Public Communal Company "Promet". Today, the situation in urban and suburban transit is very different, since there is competition on the market. Thus, apart from the Public Communal Company "Promet" the carriage of passengers on the busiest routes to Trogir and Omiš are operated by many private carriers.

Today, between 12,000 and 15,000 passengers are transported daily along the relations towards Kaštela and Trogir, by articulated buses (at time intervals of 15 to 30 minutes).

Based on the current traffic intensity, and based on the planned purposes of the surfaces in the eastern part of the city port, a forecast of the traffic flows for the planned period up to 2015 has been done. The obtained results about the passenger car movements and movements of passengers by public urban transit (at the access to the eastern part of the city from the direction of North and East), are the following:

- by passenger cars 32,351 (vehicles/day)
- by high-speed urban trains 53,513 (journeys/day)
- by buses 90,560 (journeys/day)

The great increase in the number of passenger cars, and cars for personal needs and for supplying many private companies in the city of Split contribute to the traffic chaos. The additional problem occurs due to the lack of parking space.

A special problem occurs during peak hours when the commercial speeds are substantially reduced compared to suburban relations.

The conditions of increased competition of road carriers on the transportation market of the city of Split and the railway gravitation area have brought the railway even more to the margin of the relationships in the public suburban passenger traffic.

The existing railway line from Kaštel Stari to Split, in the length of 18 km is a single-track line (except from Split to Split Predgrade, which is a double-track line). The least favourable section on the existing single-track route is between Kaštel Stari and Kaštel Sućurac (in the length of 7 km) where the construction of a crossing point is considered in order to increase the train throughput capacity for suburban traffic.

There are five railway stations on the Kaštel Stari – Split line: Kaštel Stari, Kaštel Sućurac, Solin, Split Predgrade and Split. After completing the reconstruction of the railway stations Split and Split Predgrade the double-track traffic has been introduced between those two stations, and a both-way platform was built in the tunnel cutting for the central station of the future urban railway.

### 4. BASIC CHARACTERISTICS OF CONVENTIONAL SYSTEMS IN URBAN-SUBURBAN TRAFFIC

Due to its urban and demographic characteristics, the city of Split with about 220,000 inhabitants, shows substantial traffic demand and internal mobility of its citizens. However, the mobility of the urban and surrounding suburban population is mainly met by the personal motor vehicles. The increase of the transport by personal road vehicles has been especially present over the recent post-war years, resulting in big traffic congestions, environmental pollution, increase of noise and generally, dehumanisation of urban life.

Therefore, the use of railway transport on relations

- Split – Sinj,
- Split – Kaštela – Trogir and
- Split – Stobreč – Omiš

would represent for Split and its gravitating suburban region, an important step forward in the development of the mass line transport system.

Travelling speed is a very important factor in the quality of the public urban transport. The vehicle characteristics, inter-station distances and traffic conditions also affect significantly the travelling speed. In order to indicate the advantages and the disadvantages of single modes of transport means some indicators can be presented.

**Table 1 – Travelling speed and inter-station distances in urban transport**

Type of vehicle	Inter-station distance (m)	Travelling speed (km/h)
bus – trolleybus	280 - 300	16 - 23
tramway	280 - 600	16 - 23
high-speed tramway	600 - 1500	21 - 26
underground	500 - 1500	25 - 45
urban and suburban rail	1500 - 3000	35 - 36

According to the results of the research, the rail transportation systems are 2.5 times safer than bus transport, and 24 times safer than cars.

**Table 2 – Transportation capacity and efficiency according to transport mode**

Type of vehicle	Travelling speed	Transportation capacity (places/hour)	Efficiency (1000 places / km/h)
bus – trolleybus	20.0	9000-10000	180-200
tramway	20.0	13500-18000	270-360
high-speed tramway	24.0	2000	480
underground	35.0	40000	1480
urban and suburban rail	35.0	50000	2250

**Table 3 – Characteristics of classical, urban-suburban and regional railways**

Description	Classical railway	Advanced railway	
		High-speed urban-suburban	Regional
Servicing radius	often 100	30-50 (max.)	80-00 (max)
Max. speed	80-120	80-120	80-130
Inter-station distance	5 000-10 000	1 000-3 500	7 000-12 000
Commercial speed	50-65	45-65	-80
Type of traffic	combined	separate / partly combined	usually separate
Timetable	less often per tact	per tact	per tact
Headway intervals	not constant	20, 30, 40	30-60
Platforms	low / medium	high	high / medium
Capacity (PAX/h)	depending on other transport modes	very high (up to 45,000)	high (up to 35,000)
Reliability	depending on the number, volume and level of utilisation	very high	very high
Safety	high	very high	very high
Connection to city centre	by urban transport	very favourable	by urban railway

**Table 5 – Harmful emissions**

Transport branch	Type of Transport			
	Passenger		Cargo	
	Harmful emissions (g/PAX/km)		Harmful emissions (g/ton/km)	
	CO <sub>2</sub>	NO <sub>x</sub>	CO <sub>2</sub>	NO <sub>x</sub>
Rail traffic	3	0.01	2.8	0.004
Road traffic	87	0.48	53.0	0.700

Source: Swedish Institute for Road Traffic Development, 1993

Over the past ten years, the world, and Croatia as well have seen gradual introduction of the elements contributing to the humanisation of traffic, i.e. calming down of traffic in the city centre, and increase of traffic in the suburbs. This includes a well-designed concept of traffic which has in-advance determined preferences for certain traffic participants and all the necessary elements of the traffic development, ranging from the organisation of traffic flows to traffic facilities and other elements of the urban equipment. The aim of such consideration is the introduction of new traffic modes in the urban centres, and one of

them is also the development of public urban and sub-urban railway traffic.

## 5. POSSIBILITIES OF USING THE EXISTING LINE (FROM KAŠTEL STARI TO SPLIT) FOR THE NEEDS OF URBAN RAILWAY

The basic concept of the railway junction Split lies on the three railway stations:

- Split-Grad (City) is the main passenger railway station for interurban, suburban and urban traffic;
- Split-Predgrađe (Suburb) is the railway station with multiple purposes: servicing station for train formation and vehicle maintenance, cargo station for the city, and a station for directing vehicles to the City port and the industrial zone Lora-Brodarica;
- Railway station Solin - serves to direct vehicles to the Solin area and for the industrial zones Dujmovača and Mostine, and it also represents the main cargo station for the Split area.

This route is planned to accommodate 17 urban railway stations: 5 existing ones (Kaštel Stari, Kaštel Sućurac, Solin, Split-Predgrađe and Split-Grad) and 12 new stations (Kaštel Stari, Kaštel Kambelovac, Kaštel Gomilica, Inavinil, Željezara, Sv.Kajo, Solin-širina, Dujmovača, Neslanovac, Brda, Brodogradilište and Sud).

The existing railway line from Kaštel Stari to Split, in the length of 18 km is a single-track line, except for the section from Split-Grad to Split-Predgrađe, where traffic runs on a double-track line. The line track conditioned by longitudinal natural position of the Bay of Kaštela, is laid steeply and aslant all the way to the underpass in Kaštel Kambelovac (the Kambelovac Bridge), and from there it descends via Solin and the Vranički Bay towards Split. Thus it creates an artificial division of the region into the residential and industrial zone of the surrounding area from Kaštel Sućurac to Split-Predgrađe. Although in certain sections it has shorter gradients even up to 25%, the newly reconstructed line track allows technical speed of 70 km/h and insures favourable conditions for reaching commercial speeds of suburban trains of at least 35 km/h.

By the construction of two stations, Bis and Brda in Split, the stop at the existing station Split Predgrađe would be closed (due to the small inter-station distance), so that, apart from the four existing railway stations there would be eight additional stops amounting to a total of 12 official places. The average inter-station distance would amount to about 1.6 km (although some distances between stations are shorter). The standard length of the platform would amount to 90 m, and the width would be about 3.00 m, satisfying the requirements of suburban traffic.

Possible reconstructions of the track in order to increase the capacity include:

- equipping of stations by more advanced safety systems;
- construction of crossing points between the stations of Kaštel Stari and Kaštel Sućurac on the single track railway line;
- electrification of the line, already planned for the needs of the long-distance railway traffic;
- installation of an automatic section block.

## 6. PROPOSAL OF NEW URBAN RAILWAY TRACK IN THE CITY OF SPLIT

The new urban railway track has been laid so that very complex technical conditions would be maximally satisfied:

- the line length and gradients;
- layout and altitude of the stops;
- position of the line compared to residential areas and industrial centres;
- optimal costs of construction and line exploitation.

The urban railway of Split on the section Split-Grad - Stobreč - TTTS is planned to be a double-track line, and westwards from TTTS to the connection with the existing tracks, as a single-track line. The railway line starts from the railway station Split-Grad and it is 15,184 m long.

According to the new organisation of traffic at the railway station Split-Grad two separate technological units are obtained: one for distant travelling and the other for urban railway (for which two tracks are planned). Since peak loads of urban railway do not coincide with the peak loads in long-distance trains, the handling facilities of long-distance trains can also be used for the needs of the urban railway (north-westwards).

The new urban railway has to comply with a number of requirements regarding big differences in altitudes at small distances, so that the gradient may be even up to 25 per mille. It intersects with a number of the existing (or planned) roads, and has to accommodate a large number of stops, which requires at certain sections the tunnel development of the route.

In this paper a line route is proposed that deviates by its location from the previously developed preliminary solutions. One section of the route is planned to pass through a tunnel near the hydrotechnical tunnel (which serves for transferring faecal water from the Kaštelanski Bay to the filtering device in the Stobrečko polje). From the technological aspect it would prove reasonable to construct both tunnels together. However, the need to filter the waste and faecal waters requires very urgent construction of the hydrotechnical tunnel, and this is not the case with the railway tunnel, which is still in the preliminary phase. It should be noted that the urban railway tunnel in the total length of 2,365 m will be of great influence on the volume and price of the construction works on this section.

The urban railway route forms a ring on the Split-Grad - Stobreč - TTTS - Kopolica - Split-Grad relation.

The stations are usually located in areas of the highest concentration of population and jobs. However, because of the attractiveness of this travelling mode the distance between the urban railway stations

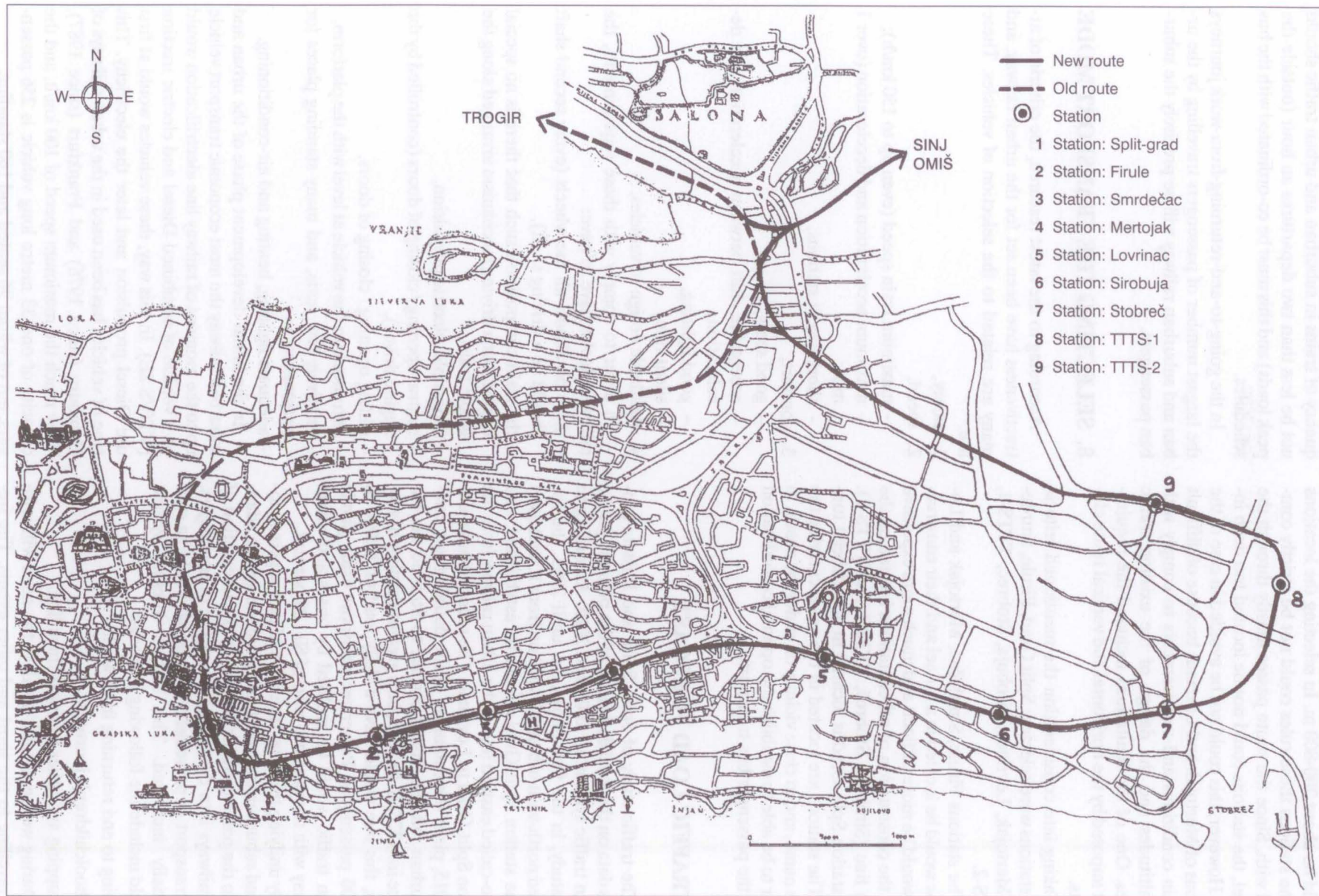


Figure 1 - The route of the new urban railway in the city of Split

should be about 700-800 m. In selecting the locations for the stations these rules could not be strictly complied with. Since the route passes mostly through the tunnel, the stations could not be located too deep inside. However, this could not be avoided in case of the stations of Mertojak and Lovrinac because of difficult terrain conditions and requirements to comply with the altitudes and the design of the existing traffic routes. One of the limitations included the requirement imposed by the horizontal and vertical route elements.

Taking into consideration the mentioned criteria nine stations were selected: Split Grad, Firule, Smrdečac, Mertojak, Lovrinac, Sirobuja, Stobreč, TTTS-1, TTTS-2.

The stations Firule, Smrdečac, Mertojak and Lovrinac would be located in a tunnel and their construction would be more difficult and much more expensive than the construction of other stations located on the open line (Sirobuja, Stobreč, TTTS-1 and TTTS-2). The station Split-Grad is located in an artificial tunnel. The stations are located in the areas carrying the same name, and in close vicinity or under the roads, in order to be able to establish the optimal co-ordination with the passenger bus transport.

## 7. TRAFFIC LOAD FORECAST

The traffic study of Split, Solin and Kaštela provides data on the total daily load of the planned public urban traffic system for 2005 and 2015. According to this study, in the first phase, i.e. until 2005, the so-called north-west urban railway line from Kaštel Stari to the station Split-Grad should be established, and the so-called eastern line of the urban railway from the station Split-Grad to Lovrinac. The second phase, until 2015, plans the extension of the double-track eastern urban rail line from Lovrinac to Stobreč, i.e. entrance into TTTS. In 2015, on a greater number of sections, this line would have a daily load of 30,000 to 40,000 passengers. Passenger transport using public urban traffic would be realised by buses and urban railway with the possible ratio of 80 : 20 percent.

By unifying the total transport of passengers in local and suburban transport into a unique system adapted to the passengers' needs and by the integration of the railways into the overall transport of passengers, the transport of passengers by railway should be substantially increased. The unique integral system should include the following journeys:

- going to and returning from work;
- schoolchildren's journeys;
- shopping and other business travelling.

During weekends and holidays the need will arise for travelling to the sport and other events. The fre-

quency of trains in suburban and urban traffic should not be less than two departures an hour (outside the peak loads) and this must be co-ordinated with the bus schedules.

In the going-to-and-returning-from-work journeys the largest number of passengers travelling by the urban and suburban railway will be precisely the suburban passengers.

## 8. SELECTING THE TRANSPORT MODE

According to the latest research, the criteria of attractiveness have been set for the urban railway, and many are related to the selection of vehicles. These are:

1. safety,
2. speed,
  - maximum train speed (even up to 150 km/h);
  - maximum acceleration and deceleration (over 1 m/s);
  - short stay at stations,
3. comfort,
  - good seats,
  - acceptable shift between acceleration and deceleration,
  - good lighting,
  - silent ride.
4. Aesthetic design of vehicles.

In order to comply with these requirements, the railway vehicles have to have:

- drive on almost all the wheels (every second shaft should be a driving shaft),
- the train composition such that there is no special engine, but a driving mechanism arranged along the whole train,
- if possible, electric propulsion,
- central opening / closing of doors (controlled by the engine driver),
- sliding opening / closing of doors,
- entrance into the vehicle at level with the platform,
- relatively few seats, and many standing places for passengers,
- adequate lighting, heating and air-conditioning.

In the initial development phase of the urban and suburban railway the most economic transport vehicle up to the moment of railway line electrification would be a vehicle of combined Diesel and electric traction (VT/VS 2E). In this way, these vehicles would at first use Diesel propulsion and later the electricity. This type of vehicles has been used in the urban railways of Hamburg (since 1976) and Frankfurt (since 1987). They reach the maximum speed of 100 km/h, and the capacity of one 33 metre long vehicle is 256 passengers, out of whom 96 seated and 160 standing.

## 9. SUBURBAN RAILWAY INVESTMENT COSTS

The following investments are necessary for the construction and opening and the first phase operation of the suburban railways:

- |  |                       |
|--|-----------------------|
| 1. Suburban railway station design                 | 100,000 HRK           |
| 2. Construction and lighting of the suburban stops | 5,337,400 HRK         |
| 3. Current value of the two Diesel Motor Trains    | 15,000,000 HRK        |
| 4. Equipment, small inventory, etc.                | <u>350,000 HRK</u>    |
| <b>Total:</b>                                      | <b>20,787,400 HRK</b> |

It has been suggested that the Croatian Railways should insure the means for technical documentation and participate with a value of one Diesel Motor Train, which would amount to approximately 40 percent of initial investments, and the rest of 60 percent of the means would be insured by the towns of Split, Solin and Kaštela.

## 10. CONCLUSION

The developing urbanisation of this area that cannot be stopped, generates daily an increasing number of travelling by passenger cars from the suburban residential areas to the centre of the city and vice versa. The entrance to the city is congested by long queues of vehicles resulting in standstills. The potential of the towns in the Split – Kaštela region, and the neighbouring towns Trogir and Podstrane, as the basic economic mover of this area, opens up real hypotheses for integrating the suburban railways into the system of public passenger transport. It is not by chance that in the Traffic Study of the Towns of Split, Solin and Kaštela, the suburban railways in this area has been marked as the backbone of the public passenger transport in the future, primarily due to the use of clean electricity, reduction of passenger vehicle traffic, reduction of noise and environmental pollution, the possibility of simultaneously carrying a larger number of passengers, preservation of the historical heritage of the towns of Split, Solin and Kaštela.

The results of the analysis show that for the urban railway route in the area of the City of Split (Grad Split) it would be necessary to construct a double-track railway line on the relations Split - Stobreč - TTTS, and a single-carriage one westwards from TTTS to the link to the existing tracks and at a different level compared to other routes. Regarding the terrain characteristics, and because of the population density the route will pass mainly through tunnels. The tunnels will be constructed partly as artificial ones

(entrenched), and partly as underground (classical) ones. The technology of constructing the stations in tunnels will be analogue to constructing the part of the tunnel in which they are located.

For traffic, it is necessary to use vehicles that can satisfy the speed (80 km/h) and maximum start-up acceleration (0.72 m/s), which can be achieved on the basis of the given distances between stations and the given deceleration (0.9 m/s). Regarding the forecast of traffic load, the frequency of trains should not be less than two departures per hour (outside peak hours) and it has to be co-ordinated with the bus schedule. Since 8 trains can pass within one hour for the headway interval of 6 minutes, and even 13 trains for the interval of 3 minutes, the needs of this area would be more than satisfied even further in the future.

The concept presented here is not only friendly oriented to humans and their freedom of movement, but it is also strongly oriented towards highly efficient technical systems of transport. This is especially true for the rail system, the development of which includes railways as well.

ANTUN STIPETIĆ, D.Sc.

NENAD KLARIĆ, B.Eng.

SLAVKO ŠERIĆ, B.Eng.

Fakultet prometnih znanosti

Vukelićeva 4, 10000 Zagreb, Republika Hrvatska

### SAŽETAK

#### PROMETNO-TEHNOLOŠKO RJEŠENJE GRADSKO I PRIGRADSKO ŽELJEZNIČKE GRADA SPLITA

*Sukladno suvremenim koncepcijama humanizacije i racionalizacije prometa sve više se provode intervencije u cilju smirivanja prometa u središnjim dijelovima grada te njegovog povećanja na rubnim dijelovima. Razvojem prijevoznih sredstava javlja se potreba redefinicije segmenta gradskog prostora uslijed povećane mobilnosti stanovnika. Jedan od efikasnih sustava organiziranja prometa je i gradska željeznica. Cilj gradske željeznice je rasterećivanje gradskih i prigradskih prometnica od prevelikog cestovnog prometa, te racionalno uklopanje u sustav javnog gradskog prijevoza.*

*Prometna mreža na splitsko-kaštelskom području uglavnom je građena u vrijeme vrlo skromnih prometnih zahtjeva, te danas ne može zadovoljiti povećane prometne potrebe. Zbog nemogućnosti bitnog povećanja kapaciteta gradskih kolnika, parkirnog prostora, kao i zbog ekoloških zahtjeva, ne treba očekivati jačanje udjela osobnog prijevoza putnika. U takvim uvjetima javni prijevoz putnika može spasiti gradsku aglomeraciju od totalnog prometnog i ekološkog kolapsa. Željeznica je upravo ta koja u budućnosti treba predstavljati okosnicu javnoga gradskoga i prigradskoga prijevoza na splitsko-kaštelskom području.*

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*željeznica, Split-Kaštela, javni gradski prijevoz, mobilnost stanovnika*

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