

The Dynamic of the Suburban Railway Passenger Transport in the Traffic System of the City of Zagreb

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Abstract—The subject of this paper is to research the dynamic and the possibilities of modelling the development of the passenger transport demand in the railway passenger suburban traffic system of the City of Zagreb and the inland railway passenger traffic in the Republic of Croatia. The researched traffic sizes by their characteristics are quantitative indicators of the railway passenger traffic transport demand, stated by the number of transported passengers and realised transport operation within the system. The appropriate mathematical and statistical analysis of passenger transport demand established the existing condition on the level of the traffic system; then, a mathematical and prognostic trend model of the researched size development dynamic was made. The prognostic trend model of the traffic size has been represented by an appropriate equation, with the calculation of the appertaining determination coefficient as a measure of quality, establishing the level of statistical significance of the given data description.

Index Terms—railway passenger demand, public urban and suburban passenger transport system, growth, development

I. INTRODUCTION

With regard to the firm correlation of the economic and traffic development, a study on the functioning and especially the dynamic of the development of the traffic system represents a major subject of scientific and research interest and work.

“Reference [1], [2] The transport demand has a crucial importance for the establishment and management of the traffic policy; moreover, it is a basic factor dimensioning the level of the traffic system development, and consequently the degree of utilisation of its technical stratum primarily, i.e. the traffic infrastructure and means of transport.

The subject of this research consists in the research of the dynamics and the possibility of modelling the mathematical and prognostic model of the railway passenger demand in the traffic system of the City of Zagreb.

The goal of the research consists in establishing the principles according to which the passenger transport demand receives their values within the function of time.

The research subject has been defined based on the research problem, i.e. to research the transport demand in the railway traffic system of the Republic of Croatia, especially in the City of Zagreb, with the goal of forming a mathematical transport demand prognostic trend model. A basic scientific hypothesis has been made: based on the conducted research, it is possible to scientifically establish the principles of the studied traffic sizes in the railway traffic system of the Republic of Croatia and the City of Zagreb and to create a mathematical and prognostic demand trend model for transportation services within the passenger traffic.

“Reference [3]” The need to establish this hypothesis ensues from the definition of the traffic system as a complex dynamic system, which is subject to rules according to the general system management theory, whereby the implementation of a mathematical theory to design the mathematical models of concrete problems is necessary in the area of traffic and transport technology for the traffic system and its subsystem management.

“Reference [4]” The traffic demand is of a stochastic character so that within the modelling it is necessary to use the methods of mathematical statistics and probability theory, also establishing the trend of the traffic size development. The trend represents a development tendency of the traffic size in time and is represented by a function of time. The transport modelling has a major role in all complex decision-making processes, especially with regard to the traffic development modelling. With regard to the dynamics in the traffic analyses of the changes in the economic and traffic system, analytical methods detecting the changes in a shorter time period are more desirable, so that the subject and the results of the research and modelling are better directed.

The application of the results of this paper is reflected in the following: a) the research results provide the decision-makers on further development of the traffic system in the studied area with a scientifically established information on the past processes providing the traffic sizes with their values, b) the applied value of this research consists in shaping a theoretic model of the traffic demand development, based on the results of the traffic size research, i.e. in formulating a functional law defining the tendency of change and direction of the traffic size development process within the traffic system,

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c) the results of the research of the studied values, established laws, as well as formed mathematical models, represent a scientifically established basis for making decisions on the traffic system development and management.

With regard to the applied method, it can be established that the paper dealt with analytical modelling of the passenger transport demand in which the models are in an analytical form (e.g. equation systems), so that the solutions are also in an analytical form. Moreover, these are stochastic models, whose behaviour cannot be predicted in advance, so that, therefore, probabilities of change in the condition of the system are defined by calculating the value of the determination coefficient.

II. SIGNIFICANCE OF THE RAILWAY PASSENGER TRANSPORT FOR THE TRAFFIC SYSTEM OF THE CITY OF ZAGREB

Within the public city and suburban passenger transport system of the City of Zagreb, the contribution of the railway transport system is rather significant. "Reference [5]" The contribution of the railways in meeting the needs of the passenger demand in the traffic system of the City of Zagreb is a consequence of the high quality level of the transport service, significant transport capacity and already known ecological advantages with regard to other transport systems, especially compared to the road traffic. The railway system significantly contributes to meeting the needs of the transport demand in a large number of European cities. Thus, according to European practice, cities, municipalities, counties and the state participate with approximately 60% in the structure of the total costs of an integrated passenger transport, while railway undertakings participate with approximately 40% (average of German, French, Belgian and Czech cities).

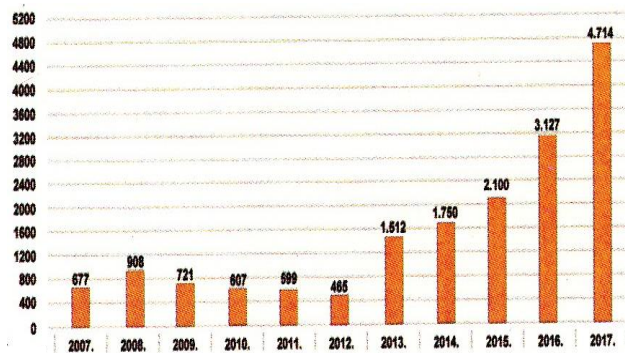


Figure 1. Investment into railway infrastructure of the Republic of Croatia for the period 2007 – 2017 (in HRK million) Source: Hrvatske željeznice (Croatian Railways), Infrastruktura (Infrastructure, Inc.) d.o.o., Zagreb, 2013

The investment in the Croatian railway infrastructure as presented in Figure 1, in the period from 2008 to 2012, was on average at the same level (approximately HRK 600-650 million per year) with a constant slight downward trend. Only since 2013 is the investment surge by more than three times evident with regard to the previous year, with plans of almost exponential investment growth by 2017.

The system of public city and suburban passenger transport is an integral part of the traffic system of Central Croatia, in which the railways comprise one of the basic transport systems (presented schematically in Fig. 2).

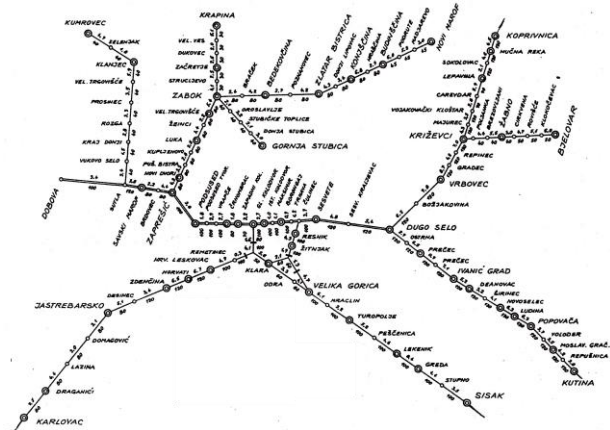


Figure 2. Schematic presentation of the railway network in the traffic system of Central Croatia. Source: Hrvatske željeznice (Croatian Railways), Infrastruktura (Infrastructure, Inc.) d.o.o., Zagreb, 2013

Central Croatia is comprised of a wider gravitation area of the City of Zagreb and the Zagreb County, as well as the surrounding counties (including the Varaždin and Međimurje counties); according to the territory that it encompasses, it makes a third of the surface of the Republic of Croatia; however, at the same time, almost a half of the nation's population lives in the area. Most certainly, Central Croatia represents a generator of the entire Croatian economic, social and political development, so that the significance of the traffic system functioning and developing in the area is thus even more significant.

III. RAILWAY PASSENGER SUBURBAN TRANSPORT OF THE CITY OF ZAGREB

The passenger railway suburban transport system has a special meaning in the traffic system of the City of Zagreb. Such a significance and the actual contribution of the railways in meeting the needs of the passenger transport needs is a consequence of several factors. The railway lines are almost ideally placed along the East-West traffic route, passing through the centre of the City of Zagreb, that, apart from being the capital of the Republic of Croatia, represents a hub of the central Croatian region. Accordingly, the developed railway network of the suburban lines can be promoted additionally with a larger number of stops within not only the suburban but also the urban area. Studying the dynamic of the railway passenger transport demand, it was established that the railway exists as a major transport system incorporated in the traffic system of the City of Zagreb.

"Reference [6]" Of special importance for the railway passenger suburban transport system of the City of Zagreb is the Savski Marof – Dugo Selo section (Fig. 3). The section is in the Mediterranean corridor of the TEN-T network and is used by passenger trains on suburban,

regional and international lines, as well as by cargo trains in international and domestic traffic. About 400 trains of a rather heterogeneous structure are present on the route daily, representing the most burdened part of the Croatian railway network.

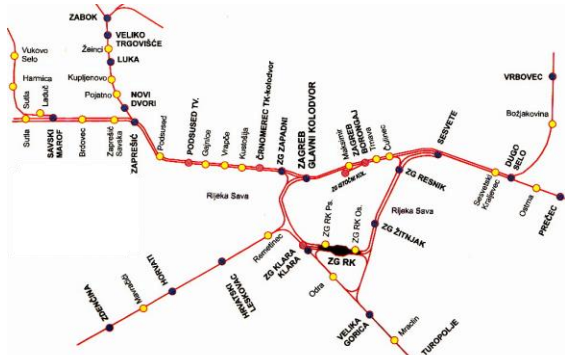


Figure 3. Schematic presentation of the railway network within the system of the city and suburban passenger transport of the City of Zagreb. Source: HŽ Infrastruktura d.o.o., (Croatian Railways, Infrastructure, Inc.) Zagreb, 2013

Legend:

- Train station
- Train stop
- Train station used for urban and suburban transport
- Railway line

Within the traffic system of the City of Zageb and its gravitational area, the public passenger transport is dominated by bus and tram transport system (within the framework of Zagrebački Holding, the Zagrebački Električni Tramvaj Subsidiary /ZagrebElectric Tram – hereinafter: ZET d.o.o.) and the railway transport system (Hrvatske željeznice Putnički prijevoz d.o.o./Croatian Railways Passenger Transport – hereinafter: HŽPP).

With regard to the application of the common tariff union since 1992, the users are able to use common passenger tickets for ZET-HŽPP (see Fig. 4).



Figure 4. Schematic presentation of tariff zones in which ZET-HŽPP tickets apply. Source: HŽ Infrastruktura d.o.o., ((Croatian Railways, Infrastructure, Inc.) 2013, according to Pintarić, Lj.: Osnovne karakteristike tržišta željezničkoga gradsko-prigradskog putničkog prijevoza / Basic Characteristics of the Urban and Suburban Railway Passenger Transport Market, HŽ Infrastruktura d.o.o., Željeznice 21, No. 2, Zagreb, 2014, p. 21-30

The system of the common ZET - HŽPP ticket, according to the structure of its transport users, is mostly comprised of workers with around 90% of the total number of passengers, while within the remaining 10% there are pupils, students, pensioners and social benefit users. Further below we will present data on the passenger demand and the realised suburban railway passenger transport operation within the traffic system of the City of Zagreb and on the domestic traffic within the Croatian railway traffic system as well as its relative share.

According to table 1, in the period 1995-2010, the average annual rate of change in the passenger demand in the domestic railway traffic at the level of the Republic of Croatia amounted to +6.2%, while for the suburban passenger traffic of the City of Zagreb it amounted to 10.5%. The analysis of the same time series for the achieved passenger transport operation shows that the average annual rate of change in the domestic railway traffic on the level of the Republic of Croatia amounted to +2.7%, while in the suburban passenger traffic of the City of Zagreb it amounted to 9.4%. The share of the suburban passenger railway traffic in the City of Zagreb according to the number of transported passengers within the domestic passenger traffic in that period has been constantly increasing from the level of 40% to the level of approximately 75% in 2008. After 2008 it was slightly reduced to 72.6%. According to the achieved passenger transport operation, the suburban passenger traffic of the City of Zagreb was around 17.7%, while at the beginning of the studied period it was up to 46.4% in the total domestic passenger traffic.

TABLE I. PASSENGER TRANSPORT DEMAND AND REALISED PASSENGER TRANSPORT OPERATION WITHIN DOMESTIC RAILWAY TRAFFIC OF THE REPUBLIC OF CROATIA AS WELL AS SUBURBAN RAILWAY PASSENGER TRAFFIC OF THE CITY OF ZAGREB

Year	Total domestic passenger transport in the railway traffic of the Republic of Croatia		Suburban railway passenger traffic of the City of Zagreb		Relative share of the suburban passenger traffic of the City of Zagreb in the total domestic traffic of the Republic of Croatia	
	Transported passengers (in 000)	Transport operation - PKM (in millions)	Transported passengers (in 000)	Transport operation - PKM (in millions)	Transported passengers (in 000)	Transport operation - PKM (in millions)
1995	27,894	1,109	11,168	196	40.04%	17.67%
1996	28,348	1,167	11,727	176	41.37%	15.08%
1997	28,113	1,120	11,782	177	41.91%	15.80%
1998	27,783	1,048	11,368	171	40.92%	16.32%
1999	32,367	1,129	15,489	232	47.85%	20.55%
2000	34,208	1,189	17,306	256	50.59%	21.53%
2001	36,246	1,167	19,533	293	53.89%	25.11%
2002	35,401	1,083	19,590	294	55.34%	27.15%
2003	35,142	1,042	19,598	294	55.77%	28.21%
2004	35,972	1,100	20,144	302	56.00%	27.45%
2005	39,104	1,161	21,151	317	54.09%	27.30%
2006	45,432	1,257	27,325	410	60.14%	32.62%
2007	62,367	1,508	44,429	666	71.24%	44.16%
2008	70,170	1,703	52,450	787	74.75%	46.21%
2009	72,846	1,745	53,908	809	74.00%	46.36%
2010	68,898	1,660	50,008	750	72.58%	45.18%

Source: Transport and Communication, Statistical Reports in 2013, No. 1517, Croatian Bureau of Statistics, Zagreb, 2014

Note: achieved passenger transport operation expressed as PKM = passenger kilometres

IV. THE DYNAMIC OF THE RAILWAY PASSENGER TRANSPORT DEMAND IN THE TRAFFIC SYSTEM OF THE CITY OF ZAGREB

The data on the number of transported passengers in the suburban railway passenger lines in the traffic system of the City of Zagreb have been processed further below by methods of mathematical statistics by means of Microsoft Excel; the data have been graphically presented with appropriate diagrams. Except for the presentation of the passenger demand in a diagram (expressed by a number of transported passengers and realised passenger transport operation) of the studied values, the appropriate mathematical and statistical processing established the prognostic trend models with the calculation of the appertaining values of the determination coefficient for each of the models. In this way, the evaluation of the level of the statistical significance of each individual model has been made possible.

The prognostic trend model of the development dynamic of the studied traffic values has been obtained by means of a computer programme, defined by a linear trend model equation and a determination coefficient (R^2) as a measure of representation, while the dynamic has been presented graphically as well. "Reference [7]" One should note that beside the size of the sample analysed in the paper ($N = 16$) the following applies: when the value of the determination coefficient R^2 is bigger than 0.388, it follows that the established mathematical model of the prognostic trend of the studied variable is statistically significant with the risk level $p < 0.01$.

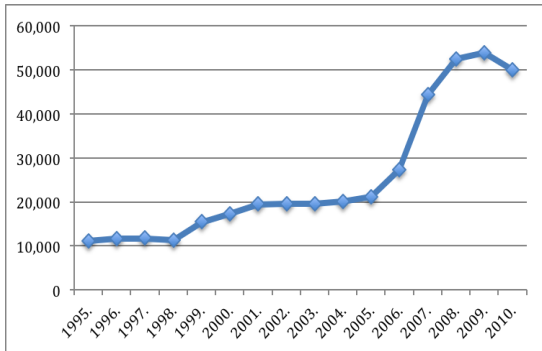


Figure 5. The number of transported passengers in the suburban railway traffic of the City of Zagreb

$$Y = 2,911.4x + 688.9 \quad (1)$$

$$R^2 = 0.801 \quad (2)$$

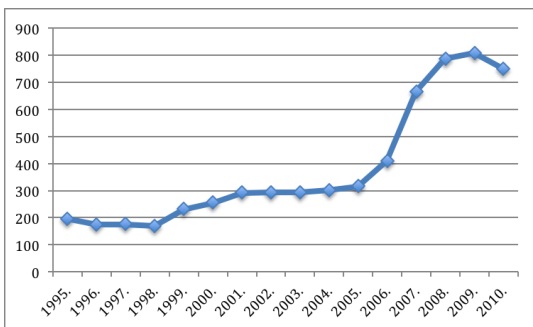


Figure 6. The realised passenger transport operation in the suburban railway traffic of the City of Zagreb

$$Y = 43,062x + 17.1 \quad (3)$$

$$R^2 = 0.789 \quad (4)$$

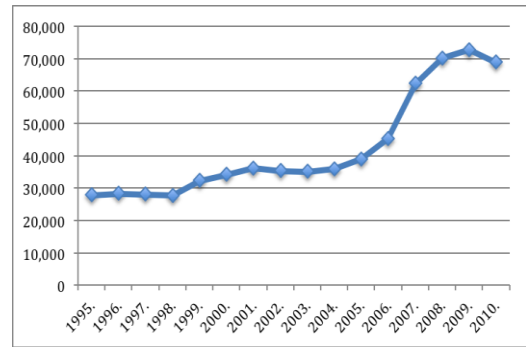


Figure 7. Transported passengers in domestic railway traffic of the Republic of Croatia

$$Y = 3062.2x + 16,490 \quad (5)$$

$$R^2 = 0.798 \quad (6)$$

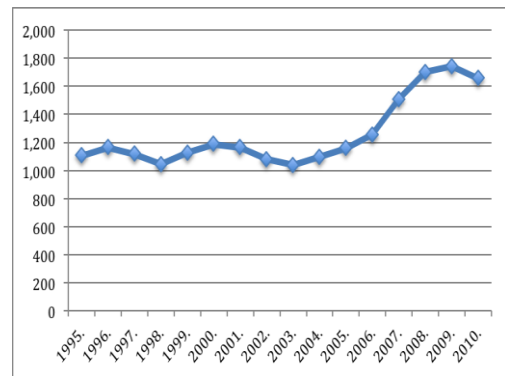


Figure 8. Realised passenger transport operation in domestic railway transport of the Republic of Croatia

$$Y = 39,479x + 926.18 \quad (7)$$

$$R^2 = 0.593 \quad (8)$$

Statistically significant mathematical prognostic trend models have been established for all the studied sizes ($p < 0.01$). The equations of these models have been expressed in the text and marked with (1), (3), (5) and (7).

V. CONCLUSION

The research has confirmed the scientific hypothesis: based on the conducted study it is possible to scientifically establish the principle of the studied traffic values in the railway traffic system of the Republic of Croatia and the City of Zagreb and to form a mathematical prognostic trend model of the demand for passenger transport services. The established mathematical prognostic trend models represent a scientifically founded basis to forecast the need for passenger transport in the railway transport system.

By analysing the passenger transport demand in the suburban railway traffic of the City of Zagreb in the studied period from 1995 to 2010, the following was established: the average annual growth rate of passenger transport demand was 10.5%, while the average annual growth rate in the achieved passenger transport operation was 9.4%.

The passenger transport demand in the domestic railway passenger traffic of the Republic of Croatia in the studied period from 1995 to 2010 grew with an average annual growth rate in the passenger transport demand of 6.2%, i.e. 2.7% of the achieved passenger transport operation.

It should also be mentioned that the intensity of the increase in the passenger demand in that period in the railway traffic of the City of Zagreb was 1.7 times bigger compared to the total domestic passenger traffic of the Republic of Croatia.

The growth intensity in the achieved passenger transport operation was as much as 3.5 times bigger in the suburban railway traffic of the City of Zagreb compared to the domestic railway traffic of the Republic of Croatia. The share of the suburban passenger traffic in the City of Zagreb according to the number of transported passengers in the domestic passenger traffic in that period has a constant growth trend, relatively increasing from the level of 40% to the level of approximately 75% in 2008. According to the achieved passenger transport operation, the suburban passenger traffic of the City of Zagreb was about 17.7% at the beginning of the studied period up to 46.4% in the total domestic railway passenger traffic of the Republic of Croatia.

By mathematical and statistical analysis of the passenger transport demand in the period 1995-2010, statistically significant trend models ($p < 0,01$) have been established for the studied values.

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