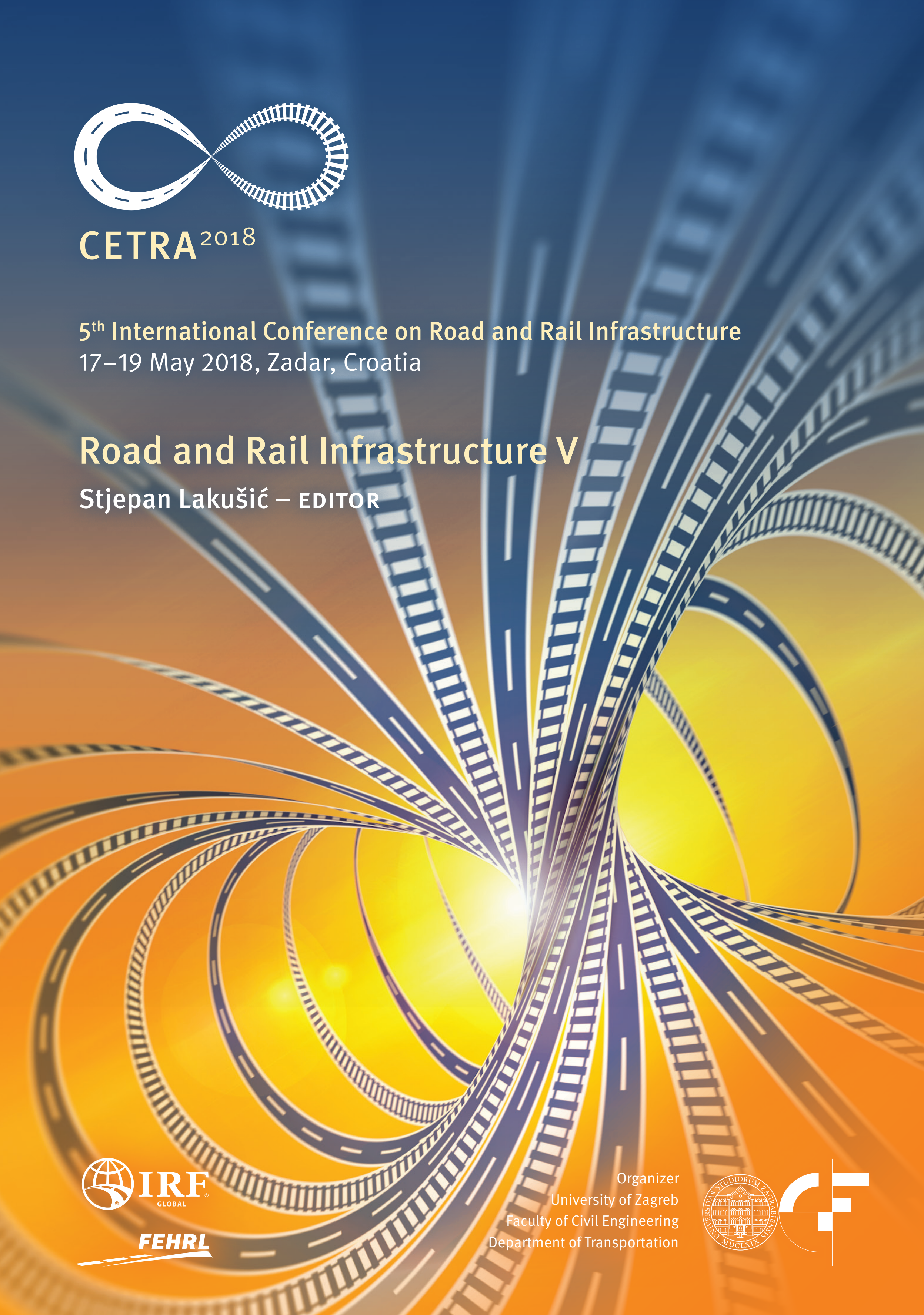

CETRA 2018

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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APPLICATION OF OSIJEK'S TRAM TRACKS GEOMETRY ANALYSIS RESULTS IN THEIR RECONSTRUCTION STRATEGY DEVELOPMENT

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Abstract

Tram system in Osijek consists of 30 km narrow-gauge tracks served by 26 trams. This backbone of urban public transport is characterized by old age of both system components – vehicles have an average age of about 50 years, and the average period from the last major track section reconstruction is 15 years. In order to ensure safe, accessible and efficient future public transport, network manager GPP Osijek has foreseen the modernization of the fleet via purchase of new low-floor trams. Of course, such investments should be made with great responsibility to the users of public transport, but also to all Osijek's citizens. It was soon concluded that the renewal of the fleet would not be able to meet the demands of modern public transport in the long run, but that the introduction of new, heavier and faster vehicles would require imminent tracks reconstruction. Due to the high cost of both system components modernization, it became of utmost importance for manager to establish the tenable strategy i.e. the dynamics of the phased approach to tramway network reconstruction. Since track geometry is one of the most important factors for ensuring a safe and comfortable ride, effective planning of phased tracks reconstruction is impossible without the knowledge of its condition and quality across the entire network. This paper describes the procedure and results of the measurement and analysis of the narrow-gauge tram tracks geometry in Osijek, carried out to determine the required investment dynamics in their reconstruction.

Keywords: tram tracks, track geometry, reconstruction planning strategy

1 Introduction

In the last few decades, a growing number of cities are (re)turning to the tram as an efficient, adaptable and environmentally friendly mean of urban public transport [1, 2]. Osijek, the fourth largest city in Croatia and the only one apart nations' capital Zagreb that still incorporates trams in urban public transport system, is no exception.

Today, tram system in Osijek consists of 30 km narrow-gauge tracks, on which transport is organized within two tram lines serving 44 stations by 26 trams (17 Tatra T3RPV_O and 9 Düwag GT-6 type trams). This backbone of urban public transport, with approximately 6.5 million passengers transported each year [3], is characterized by old age of both system components – infrastructure and vehicles, with construction and design technology dating from the 1960's. Because of that, the networks manager GPP Osijek d.o.o. expects that the upcoming years could bring potential problems within the unhindered provision of passenger transport services.

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To ensure safe, accessible and efficient future public tram transport, the manager has foreseen the modernization of the fleet via purchase of new low-floor trams. It was soon concluded that simply renewing the fleet in the long run will not yield the desired effect of establishing a sustainable urban transport system, and that the introduction of new, heavier and faster tram vehicles would require imminent tracks reconstruction. Due to the high cost of both system components modernization, it became of utmost importance for manager to establish the tenable track modernisation strategy i.e. the dynamics of the phased approach to tram network reconstruction.

Since track geometry quality is the most important factor for ensuring a safe and comfortable ride, knowledge of the synthetic track geometry quality coefficients across the entire tram network is required to take the economically justified decisions connected with planning of major reconstruction of the track sections [4]. This paper describes the procedure and results of the measurement and analysis of the narrow-gauge tram tracks geometry in Osijek, carried out to determine the required investment dynamics in their reconstruction.

2 Tram track geometry

2.1 Tram track geometry parameters

In general, track geometry is defined by the following five parameters: gauge, cant, twist, and horizontal and vertical track irregularities [5, 6]. Track gauge (G) is defined as the distance between the gauge faces of the two adjacent running rails measured at a prescribed distance below the running surface.

Track cant or cross-level (C) is defined as the difference in the height of the adjacent running surface computed from the angle between the running surface and a horizontal reference plane. It is expressed as the height of the vertical leg of the right-angled triangle having a hypotenuse that relates to the nominal track gauge plus the width of the rail head rounded to the nearest 10 mm.

Track twist (T) is defined as the algebraic difference between two cross levels taken at a defined distance apart, usually expressed as a gradient between the two points of measurement. Horizontal track irregularities or alignment (Y) is defined as the deviation of the rail head in the horizontal plane from the average longitudinal axis of the rails in the tangential section of track (in curves the direction is observed depending on the curve radius). Vertical track irregularities or longitudinal level (Z) is defined as the vertical deviation of the rail running surface expressed by deviation from the mean vertical position of the rails.

2.2 Tram track geometry measurement

Measurements of Osijek tram tracks geometry parameters were carried out during November 2016 by electronic measuring trolley TEC-1000 manufactured by GRAW Sp.z.o.o. This is a device for manual continuous measurement of track geometry whose structure consists of transverse and longitudinal beam, supported by three rollers, and the control unit, i.e. data logger. Measuring elements include inductive linear motion sensors for measuring track gauge as well as horizontal and vertical track irregularities, and an electronic inclination needle for cant measuring. Track twist is calculated during measurements as the algebraic difference between two consecutive cant values 10 m apart (5 m in front and behind the measurement cross section) [7]. The measurements were recorded with a 1.0 m resolution, as a function of track chainage. Continuous measurements along the tracks included a total of 27520 consecutive georeferenced track cross sections. During measurements, each of the track measuring profiles was assigned with the value (signal) of the five before mentioned track geometry parameters and track chainage. For the purpose of measured data processing and analysis, after data transfer from the TEC-1000 logger to PC, conversion to Excel format was performed by specialized Track Gauge software.

2.3 Five parameter geometry defectiveness coefficient W_5

When evaluating the quality of the Osijek tram tracks geometry, the total effect of all five geometry parameters was considered by synthesizing all recorded geometry defectiveness into so-called five parameter track defectiveness coefficient W_5 [4]. This is a quality index for track geometry, a non-dimensional computational value, characteristic of each analysed track section. It is derived from calculated defectiveness of five track geometry parameters as:

$$W_5 = 1 - \left(1 - W_G\right)\left(1 - W_C\right)\left(1 - W_W\right)\left(1 - W_Z\right)\left(1 - W_Y\right) \tag{1}$$

The formula treats the defectiveness of each geometry parameter as an independent event in practice where W_G represents defectiveness of gauge, W_C defectiveness of cant, W_W defectiveness of twist, and W_Z and W_Y are arithmetic averages for vertical and horizontal irregularities determined from the defectiveness of left and right rail. These relative quality coefficients (defectiveness) for each track geometry parameter are calculated from the relation:

$$W = \frac{N_p}{N} \tag{2}$$

N represents total number of signal samples along the analysed track section, and N_p number of signal samples exceeding the allowable limits (geometry defectiveness tolerances) within the analysed track section given in Table 1 [8].

Table 1 Allowable tram track geometry parameters defectiveness tolerances

Parameter / defectiveness	Min	Max
Gauge [mm]	-2	+15
Cant [mm]	-8	+8
Twist [mm/m]	-3	+3
Horizontal irregularities [mm]	-15	+15
Vertical irregularities [mm]	-15	+15

3 Track defectiveness coefficient progression

Before calculating the track geometry defectiveness coefficient W_5 for the purpose of track geometry exploitation behaviour analysis, whose results would serve to estimate further behaviour of geometry quality and elaborate maintenance strategy, it was necessary to perform track segmentation i.e. to define appropriate analytical and maintenance sections [9].

3.1 Tram network segmentation

The linear tram track infrastructure was divided into sections with homogeneous characteristics of exploitation periods and the type of track construction. Segmentation was carried out in three steps.

In the first step, based on the tram timetables and their physical characteristics, trams annual number and average weight were defined. These values were then used to identify track segments which are, on an annual level, exposed to different loads i.e. segments' annual exploitation intensity expressed in million gross tonnes (MGT/year).

In the second step, the periods of track exploitation defined by years passed from individual track segment construction or its last reconstruction were taken into account to express the segments' cumulative exploitation intensity in million gross tonnes (MGT).
The third step considered built-in elements and track construction materials. Table 2 shows a schematic cross-section of the track superstructures three main elements that characterize a particular type (I to V) of tramway construction.

Table 2 Tram track superstructure elements and defined construction type

1	2	3	**Construction type**
Bearing layer	Rail fastening system	Rail enclosure	
Concrete slab	Indirect elastic	Gravel	I
	Direct elastic	**Pavement**	II
	Indirect elastic		III
	Embedded rail		IV
Ballast bed	Transverse rods	Gravel	V

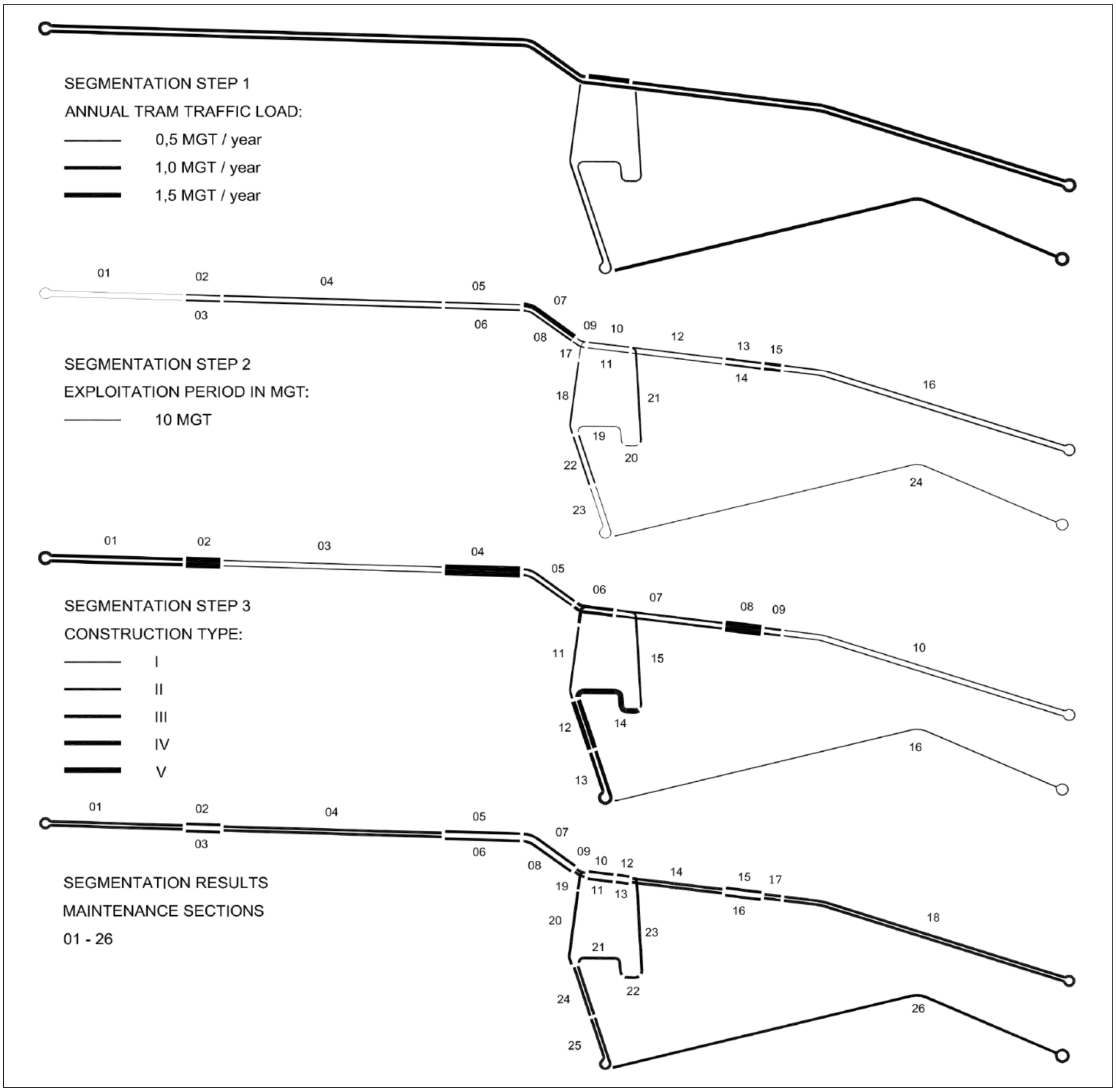


Figure 1 Tram network segmentation steps resulting in defined maintenance sections

Steps and results of performed track segmentation are shown on scheme given in Fig.1. In regard to annual tram load, exploitation period in MGT, and construction type, Osijek tram network was divided in 26 maintenance sections.

3.2 Track defectiveness coefficient progression rate

In determining the progression rate, i.e. increase, of W_5 value during exploitation, it was accepted that the gradual degradation of the track geometry is linear by nature [10]. For each analytical section the W_5 value was calculated and then divided by section exploitation period value in MGT. In this way, the increase of the coefficient W_5 in a unit of exploitation period was determined for each section (Table 3.).
The calculated values were then grouped according to the track section construction type, and their weighted mean was then defined (Table 4.). These mean values of W_5 increase per MGT will be used in the simulation of the future track geometry quality behaviour.

Table 3 Maintenance sections database

Maintenance section	Section length [m]	W_5	Constr. type	MGT per year	Expl. period [year]	Expl. period [MGT]	W_5 per MGT
01	2452	0.12	III	1.0	3	3.0	0.04
02	324	0.73	V	1.0	12	12.0	0.07
…							
12	154	0.66	II	1.5	9	13.5	0.05
…							
24	952	0.71	IV	0.5	27	13.5	0.06
25	849	0.18	III	0.5	11	5.5	0.04
26	4622	0.17	I	1.0	8	8.0	0.03

Table 4 Mean W_5 values for different tram track construction types

Constr. type	% of network	W_5 – weighted mean	W_5 per MGT – weighted mean
I	50.2	0.18	0.02
II	18.4	0.84	0.06
III	15.3	0.17	0.04
IV	3.5	0.71	0.06
V	12.7	0.70	0.06

4 Results

During track geometry quality degradation simulation, track sections reconstruction intervals were calculated according to the following assumptions:

- track geometry degradation is linear by nature [10];
- annual exploitation intensity along network will not change significantly in the future;
- track reconstruction should be planned when W_5 values reach 0.6 [4];
- initial value of W_5=0.1 will be guaranteed immediately after track section reconstruction [4];
- geometry of track sections with construction type I and III will degrade in their own established un-averaged rate, even after reconstruction;
- tracks with current construction type V will be reconstructed as type I, and tracks with current construction type II and IV will be reconstructed as type III, since the analysis has shown that geometry degradation of tracks with type I and III construction is much slower, and will progress as shown in Fig. 2.

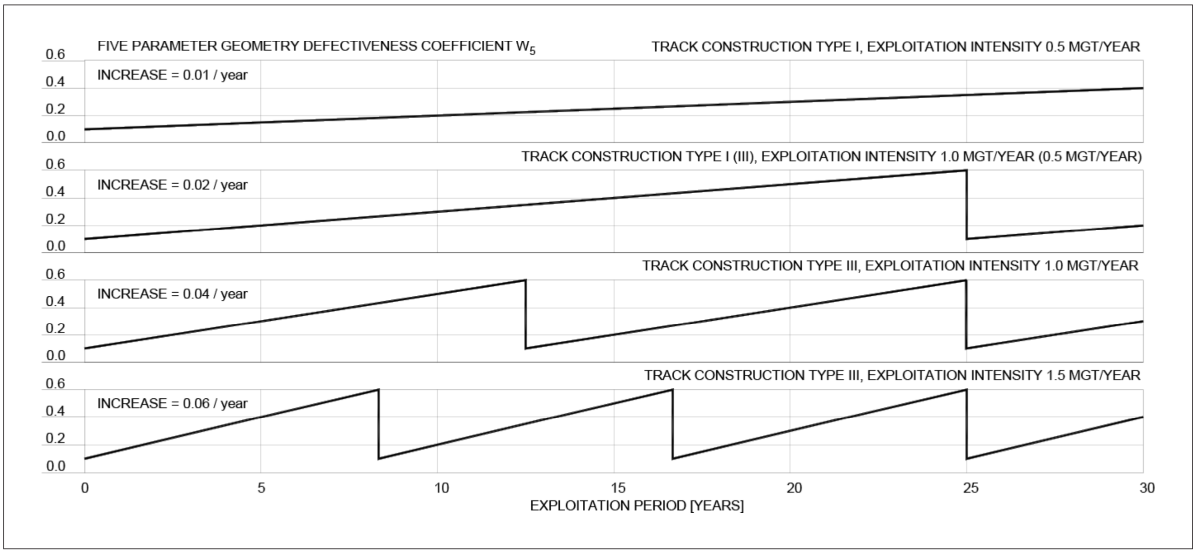
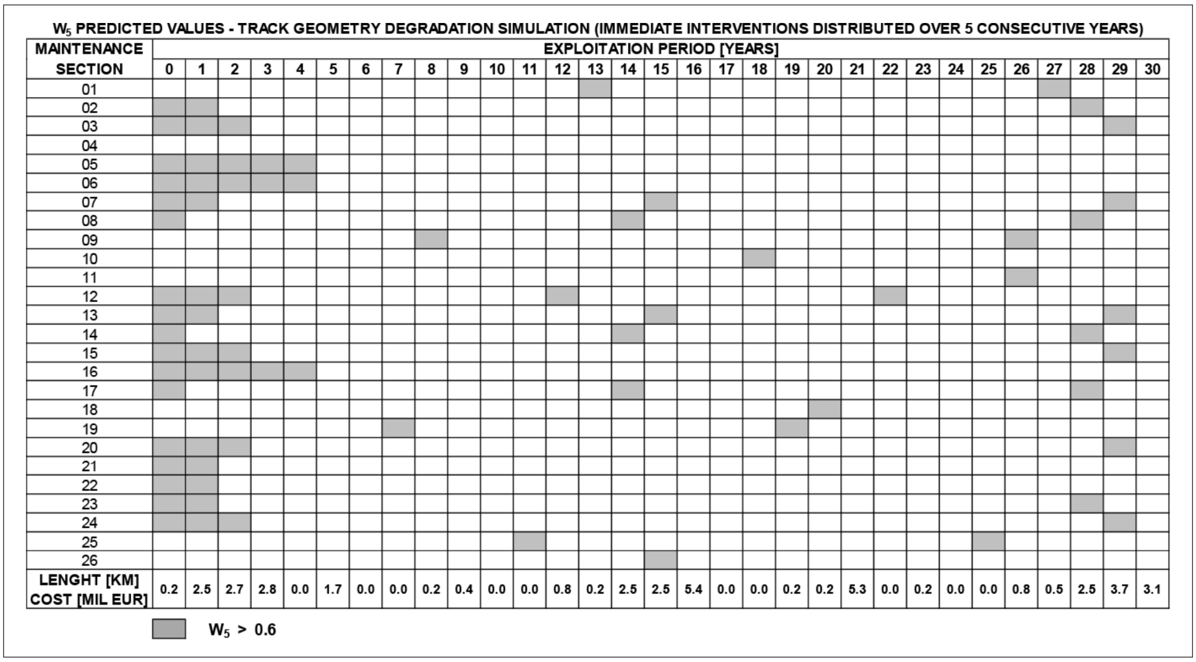


Figure 2 Calculated Osijek coefficient W_5 mean annual increase

Fig. 3 shows a part of created editable maintenance sections database. It contains the values of coefficient W_5 calculated from measured geometry parameters, paired with information about their location on the network, track section length, and current track construction type. Using the appropriate algorithm for coefficient W_5 mean increase, typical for each track construction type and the sections' annual track load in MGT/year, this database was used to simulate possible track geometry quality degradation for each maintenance section. In addition to the estimation of the term (year of track exploitation period) in which, due to the poor track geometry quality, it will be necessary to reconstruct the track section, the database application allows for the rough estimation of the investments needed, based on the known lengths and locations of the sections. Shown simulation results are just one of the many possible track geometry quality management solutions. It is a responsibility of Osijek tram system manager to determine realistic timing and feasible length of tracks reconstruction in order to optimize annual investments in the design, organization and performance of construction works, and their impact on the regular public transport service.



W_5 PREDICTED VALUES - TRACK GEOMETRY DEGRADATION SIMULATION (IMMEDIATE INTERVENTIONS DISTRIBUTED OVER 5 CONSECUTIVE YEARS)

MAINTENANCE	EXPLOITATION PERIOD [YEARS]																														
SECTION	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
01														▨														▨			
02	▨	▨																											▨		
03	▨	▨	▨																											▨	
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LENGHT [KM] COST [MIL EUR]	0.2	2.5	2.7	2.8	0.0	1.7	0.0	0.0	0.2	0.4	0.0	0.0	0.8	0.2	2.5	2.5	5.4	0.0	0.0	0.2	0.2	5.3	0.0	0.2	0.0	0.0	0.8	0.5	2.5	3.7	3.1

▨ $W_5 > 0.6$

Figure 3 W_5 predicted values and advised future interventions timing

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