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Road and Rail Infrastructure II

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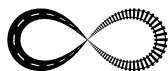
EFFECTS OF TRAM TRACK DESIGN AND EXPLOITATION PARAMETERS ON GAUGE DIVERGENCE

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Abstract

The main objectives of the tram track design process are the rational use of urban traffic areas, while ensuring a safe and comfortable ride and long exploitation life. Generally, the guidelines for the design and maintenance of tram tracks in Zagreb, as a special group of track structures, have been developed based on engineering practices and experiences gained in the design and maintenance of railway systems. According to these guidelines, an important parameter in determining the needs for rehabilitation of tram tracks is the track gauge. The paper describes the examination of the impact of traffic volume, horizontal geometry design and incorporated elements of track superstructure on the increase in gauge divergence as decisive factor for the track reconstruction. The study is based on ten–year follow–up of changes of the tram tracks gauge. By classification and analysis of data collected by gauge measuring at more than 7 km of Zagreb tram tracks the impact of the route design and traffic volume on the process of track degradation is defined.

Keywords: tram track, gauge measurement, horizontal geometry, superstructure, traffic volume

1 Introduction

Tram network, in total length of 116 346 m, is the backbone of public transport in the Croatian's capital Zagreb – annually trams transport about 204 million passengers [1]. Individual tram lines in the city centre are exposed to traffic of 15 MGT/year, with the tram passing frequency under one minute [2]. Today, an increasing emphasis on reducing tram infrastructure management costs requires optimization of each step of operations, including track maintenance. The main objectives of track maintenance optimization are to decrease maintenance costs and increase track life length while assuring high safety standards. This can only be achieved through the creation and implementation of effective maintenance strategies.

One of the main parameters to assure safe and comfortable tram service is to maintain high quality of track geometry [3]. Track geometry – longitudinal level and horizontal curvature of both rails, track gauge, cross–level (superelevation) and track twist – represents one of the crucial track condition parameters, closely related to many other degradation phenomena, and is often used for triggering the whole range of track maintenance and renewal activities [4]. The first step in optimizing track geometry maintenance is to estimate the track degradation rate in order to properly schedule maintenance activities [5]. This requires a systematic monitoring of track geometry. The analysis of the evolution of the track geometric parameters allows to identify both the poor performance sections and the variation of the conditions of one delimited track section along the time [6].

Many attempts have been made to better understand the track geometry degradation and create empirical models for degradation mostly by the Railway Research Institutes like ERRI – European Rail Research Institute in Netherlands, TTCI in USA, RTRI in Japan, TU Graz in Austria, etc. [5]. Howe-

ver, the knowledge obtained in the field of 'big railways' can not be directly applied to the 'small tracks' in urban areas intended for public transport. Also, because of the significant differences between numerous types of urban tracks in the world, it is difficult to establish universal rules of tram track geometry degradation in service. Table 1 shows the basic differences between the 'big' and 'small' railway systems on the example of the Zagreb tram system [7, 8].

Table 1   Characteristics of Zagreb's tram tracks

Characteristic	Zagreb's tram tracks
Location	Close proximity to the adjacent buildings, interference with the urban infrastructure.
Geometry	Track gauge = 1000mm (+3mm, -2mm), minimum horizontal curve radius = 17 m, maximum slope = 7%.
Superstructure	Grooved rail Ri-60 embedded in gravel, asphalt or precasted reinforced concrete slabs.
Vehicles	6 types of vehicles (different age, capacity, weight, wheel profile).
Traffic	Diversity of the priority and running speed.

This paper describes an attempt to define a trend of increasing tram tracks gauge, as one of the most important factors of safety and driving comfort, during exploitation. The track gauge will tend to widen through natural wear, primarily in curves. Within a short time after rail installation or re–profiling an initial phase of high abrasion that occurs as the rail head's shape conforms to passing wheel flanges is followed by more moderate wear whose growth rate depends on a number of influential factors. These influential factors of track geometry degradation can be divided to the structure factors (e.g. steel rails driving surface hardness), geometry factors (e.g. horizontal curve radius) and traffic factors (e.g. traffic volume) [6, 9, 10].

Regression analysis of track gauge divergence along the four sections of Zagreb's tram tracks, in total length of about 7 km, preformed by taking into account historical data about previously mentioned degradation factors, gave us an estimation of the track behaviour during exploitation. Preformed statistical analysis enabled the comparison of gauge values measured at different times of operation and establishment of a correlation between speed of track degradation, exploitation conditions, track geometry and incorporated elements of track structure. Described research could in future contribute to defining the general maintenance policy or improvement of decision–making process during maintenance planning on tram tracks in Zagreb.

2 Analysis

According to the literature, the most efficient methods to asses the track condition as a function of a number of independent variables, such as preformed maintenance, traffic volume, integrated permanent way elements and designed track geometry, are empirical or mechanistic–empirical degradation studies and macro–analysis carried out using regression techniques [6, 9]. Due to great diversity of these variables along the tram network, the question is how to, in order to better understand the behaviour of tram infrastructure during exploitation, effectively use the information on these variables. The answer to this question lies in the segmentation process, by which the linear infrastructure is divided into segments, and all abovementioned information is aggregated and associated to them [4]. Conducted research sought to determine the accuracy of estimation of track gauge divergence depending on the amount of information associated with the observed sections of the network (i.e. the level of segmentation) and whether prediction accuracy increases with increasing number of variables associated to the section's segment.

If we exclude sections with high deterioration rates, usually track geometry deteriorates linearly with tonnage or time between maintenance operations [3, 10]. However, more recent

studies revealed that the geometry deteriorates exponentially [5]. Due to these discrepancies in previous research results, analysis described in this paper was performed using linear, polynomial and exponential (power) regression over mean gauge divergence from the designed value of 1000 mm.

3 Overview and collection of input data

Zagreb, like many other European cities, has till this day retained the traditional, narrow–gauge tram system whose origins date back to before World War I. As a rule, desire to modernize the management process of such systems faces problems with documenting infrastructure as a precondition for its proper maintenance and development planning [11]. To carry out an overall evaluation of the track quality and identify characteristic track behaviour during exploitation it is necessary to possess comprehensive historical database about construction, maintenance and exploitation of the network [6, 12].

Historical data on the geometry and structure elements of the analyzed four sections of Zagreb's tram network were collected on the basis of supervision reports made during reconstruction of tracks 3 and 4 (completed in June 1997) and construction of tracks 1 and 2 (completed in October 2000). Initial track gauge measurements performed immediately after the track re/construction at every 1m' of track (in places of rail bearings) defined the initial, baseline condition of the track gauge before the exploitation. The gauge values needed to perform the analysis, i.e. to which reference values of the initial gauge will be compared to, were measured during spring of 2011 by means of digital track geometry measuring device GRAW DTG TET 1000. Based on the collected and measured values of gauge, the change (increase) of gauge divergence from the designed value was calculated in each measurement point of the tracks.

In regression analysis the speed of gauge degradation can be observed as a function of time and/or intensity of track exploitation [5]. The traffic volume at observed sections that passed between initial and gauge measurements conducted for this research was defined on the basis of tram timetables [7], taking into account the characteristics (weight and capacity) of different types of vehicles that operate on observed tram tracks [13]. Due to the lack of precise historical data necessary for calculating the total amount of tons transported on the observed tracks, the following assumptions concerning the transport capacity were adopted:

· vehicles operate 18 hours per day,
· on weekday amount of passenger load is 130% of the tram capacity during 6 hours and 40% during 12 hours,
· on non–working day amount of passenger load is 40% of the tram capacity during all 18 hours,
· average weight of one passenger is 70 kg.

Also, only the approximate time i.e. the pace of replacement of some older types of trams (GT6, KT4) with more modern low–floor trams (TMC 2200), which began in 2005, could be incorporated into calculation.

Table 2 Calculated traffic volume on observed tram tracks

Gauge measurements	Tram track	Trams per week	Total number of trams	Traffic volume [mil t]
October 2000. June 2011.	1	1.607	531.456	37.01
	2	1.715	935.936	39.50
June 1997. April 2011.	3	1.875	1.320.530	42.69
	4	1.959	1.379.792	44.66

4 Regression analysis

4.1 Levels of the regression analysis (track segmentation)

Regression analysis was performed over the mean values of gauge divergence from the designed width for three levels of analysis or three degrees of track segmentation (Figure 1). Minuteness of the segmentation i.e. the number of observed types of track, depending on the number of associated information about the influential factors of gauge degradation, gradually increases from first to third level as follows.
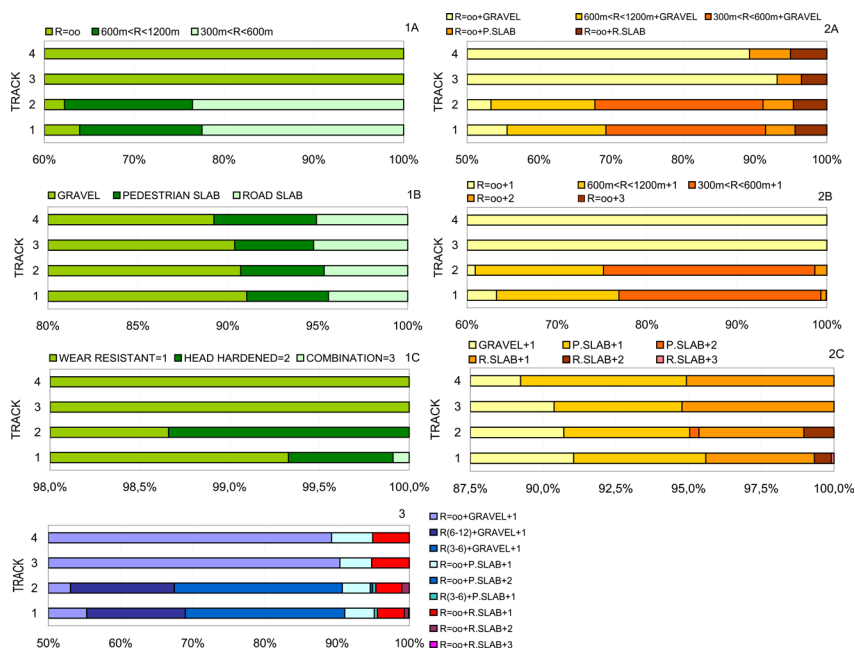
Figure 1   The prevalence of each type of track at observed sections for different levels of segmentation

In first level of analysis tracks were divided into segments according to:
a   horizontal alignment – linear segment and curve segments with radius from 600 to 1200 m, 300 to 600 m and less than 300 m (4 track types);
b   rail embedding structure – tracks embedded in gravel, asphalt or precasted reinforced concrete slabs (3 track types);
c   rail steel quality – wear–resistant rails, head hardened rails and their combination (3 track types).

In second level of analysis tracks were divided into segments according to possible combinations of:
a   horizontal alignment and rail embedding structure (12 track types);
b   horizontal alignment and rail steel quality (12 track types);
c   rail embedding structure and rail steel quality (9 track types).

In third level of analysis tracks were segmented according to all possible different combinations of observed gauge deterioration influential parameters: horizontal alignment, rail embedding structure and rail steel quality. This resulted in identifying 36 possible track types on which to perform the regression analysis.

4.2 Regression analysis

After defining the traffic volume for each track, the track segments for each level of analysis and the mean value of gauge divergence for each track segment, regression analysis was performed. Linear, polynomial and power regression was applied to a total of 15 different segments identified at observed four tram tracks, followed by analysis of the results in the form of comparison of regression coefficients.
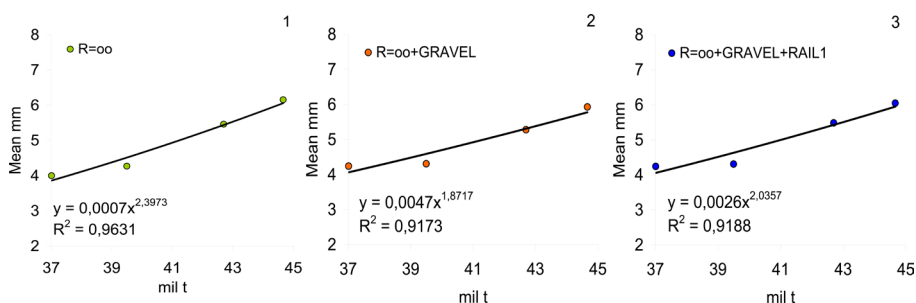
Figure 2   Power regression charts for each level of analysis (1st – linear track segment, 2nd – linear track segment with rails embedded in gravel, 3rd – linear track segment with wear–resistant rails embedded in gravel)

4.3 Results of the analysis
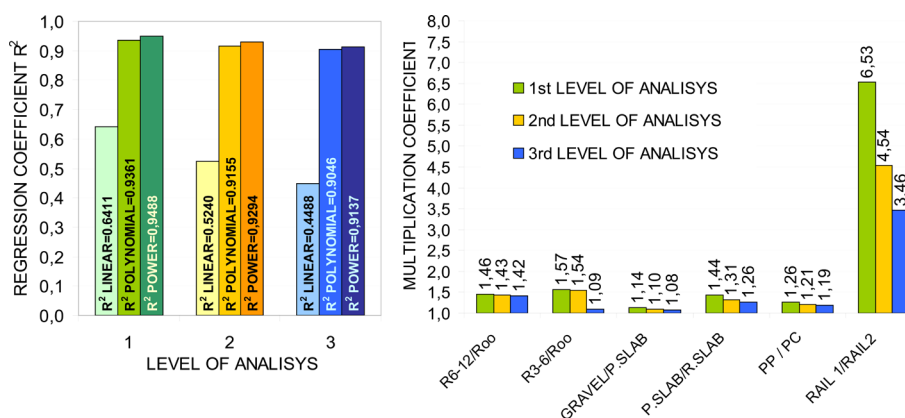
Figure 3   Calculated average regression coefficients (left); multiplication factors for mean gauge divergence increase (right)

Figure 3 (left) shows the calculated average values of linear, polynomial and power regression coefficients. It is clear that second–degree polynomial and power function describe the change or increase in gauge divergence due to increasing (cumulative) volume of traffic considerably better than simple linear function. It can also be seen that the reliability of gauge divergence estimation slightly decreases with increasing track segmentation i.e. level of analysis.

Figure 3 (right) shows the multiplication factors for mean gauge divergence increase depending on the track type and level of analysis. As it was expected, further analysis of mean gauge divergence on different track segments showed that the increase of gauge divergence, after the same amount of cumulative traffic volume, is greater on tracks in curves, constructed

using rails of lesser quality embedded in gravel. The diagram shows that increase in level of analysis and track segmentation decreases multiplication factor for gauge divergence between different types of tracks. Also, at higher–level analysis, lower mean gauge divergence values are obtained using regression equations. From the above it can be concluded that with increasing level of segmentation we can predict the future state of the track with more precision.

5 Conclusions

Many foreign researches are examining the effects of track geometry degradation influential parameters on track maintenance and renewal. Adoption of best foreign practice in maintenance is more preferable than attempting to conduct wholly local studies. Nevertheless, results of most of these researches can't be directly applied because of the differences in Zagreb's tram vehicle and track characteristics which have been identified as key parameters [14]. It is therefore necessary to conduct own research to determine the applicability of foreign results in the local conditions.

The regression analysis described in this paper has shown that we can with approximately 90% confidence claim that gauge width in longitudinal sections of tracks composed of wear–resistant rails embedded in gravel will increase by 1 mm after passage of 19 mil. t of traffic volume. In case of tracks embedded in precasted reinforced concrete slabs, the same increase will occur after passage of 30 mil. t.

Results of described trend analysis must be considered with certain caution. A possible source of error is the use of different gauge measurement instruments during initial and final measurements. Another source of error are the possible positioning deviations of measurement points [15]. The accuracy of the analysis is also reduced by the adopted assumptions about the structure of tram vehicles in operation on observed tracks, and the fact that these tracks form a very small part of Zagreb's tram network (only 6% of the total network length is covered by the research). However, it can be considered that the impact of these inaccuracies is sufficiently reduced by use of mean gauge divergence values calculated for the tracks with similar characteristics

Another question that arises is the applicability of the approach described in this paper compared to the application of finite element modelling and dynamic modelling of track degradation. These models are not limited to static analyses and may be utilized to model discrete track components and determine the interaction between them, as well as the stresses; however, they are computationally expensive, they cannot be changed quickly to represent different track layouts or different loading conditions and can only present results for the specific vehicle and track under consideration.

The choice of approach should therefore be taken in light of what the results of the track geometry deterioration models are to be used for [15]. For use within maintenance decisions on a daily basis, deterministic model described in this paper, although it could hardly take into account every possible situation on the track, might be a good contribution to reducing uncertainty in predicting the track gauge deviation through time.

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