TRACK GAUGE MONITORING SCOPE OPTIMIZATION ON SMALL URBAN RAILWAY SYSTEMS

Igor Majstorović, Maja Ahac, Stjepan Lakušić
University of Zagreb, Faculty of Civil Engineering, Croatia

Abstract

Urban transport plays a key role in the sustainable development of large cities. Urban railway systems, as eco-friendly mass transport systems, are becoming the basis of urban traffic development. Maintaining a high-quality service with continuously increasing traffic demand places an additional burden on public transport operators. Track geometry control has a major impact on availability and maintenance costs of public transport. Good management of rail infrastructure involves continuous monitoring of track geometry (track gauge, cant, twist, horizontal and vertical irregularities) where surveying should be done up to several times a year. Measuring of track geometry in chosen track cross-sections can be done automatically with relatively expensive equipment, or manually which is cheaper but takes longer. Therefore, the question arose as to whether it is possible on small urban railway networks to reduce monitoring scope by increasing of sampling distance, and if so, what should be recommended sampling distance. This paper presents, on the example of the City of Osijek tramway system, how changes in sampling distance effects on track gauge parameter. The results of the conducted analyses are presented and discussed. The recommendations on track gauge monitoring scope optimization on small urban networks are made.

Keywords: track geometry, track gauge; monitoring scope, sampling distance, urban railway system

1 Introduction

Two main objectives in the planning of modern urban transport systems are efficiency and sustainability. As rail systems are being recognized as eco-friendly mass transport systems, they are once again becoming the basis for urban area development and the backbone of urban transport systems [1]. The most popular urban railway transport system is the tramway transport system. Trams are electrically powered, usually lighter, and shorter than light or conventional rail vehicles, and they can share their route with other vehicles. These features make them more accessible for passengers in the historical city centres with narrow and winding streets.

With the annual increase in traffic demand, tram infrastructure needs to bear more load. This results in higher rates of tram track degradation. To ensure quality, and therefore safety and reliability of the system, the tracks must be continuously monitored and cost-effectively maintained. The key parameter in track quality assessment is the quality of track geometry. According to European Standard EN 13848-1 [2], it is presented as an assessment of deviation from the mean or designed track geometrical characteristics in the vertical and lateral plane which can raise safety concerns or have a correlation with the ride quality. To assess

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track geometry quality, in total five geometric parameters need to be measured along the tracks: track gauge, longitudinal level, cross level, alignment, and twist. These parameters must be recorded as a consecutive set of data sampled at a constant distance-based interval not larger than 0,5 meters [2].

Track irregularities are usually measured with track-recording vehicles or cars (TRV or TRC) equipped with inertia-based measurement systems, which use accelerometers, gyroscopes, and lasers to record the track geometry and irregularities. Track irregularities can be estimated through numerical methods that are based on data collected with accelerometers mounted on the axle boxes, bogie frames, and in the car bodies of in-service trains [3].

Small urban railway system administrators usually do not have such sophisticated and expensive track maintenance machines, but the recording of the track geometry is carried out manually using a measuring trolley or a measuring rod. For manually operated devices each measurement needs to be recorded as a single value [1]. Unlike measuring vehicles, which can record the track geometry at relatively high speeds during operating hours, manual measurements are relatively slow and can affect the timetable if the measurements are not carried out without interruption of regular operations.

To ensure optimal allocation of resources for the railway infrastructure maintenance, it is necessary to continuously monitor the track geometry quality. However, given that monitoring is both time-consuming and costly [4, 5, 6], the main question is how frequently, both in time and space, measurements of the tram track geometry should be performed. The focus of this paper is on the evaluation of this sampling distance, defined by [2] as the traveled distance between any two consecutive measurement points on the same rail, for tram track geometry measurements done with manually operated devices. The main objective is to propose monitoring scope optimization for small urban rail systems by increasing the track geometry sampling distance. For this purpose, the geometry parameters of tram tracks in the City of Osijek were analysed. The data was collected in November 2016 for “Tramway track condition analysis on GPP Osijek tram network” study [7]. Although track geometry quality assessment is based on five track parameters, in this paper the focus was only on track gauge. The analysis was carried out separately for 3 identified network sections, and a total of 140 200-meters-long track segments using different sampling distances. By comparing the results of the analysis conducted for initial and different increased track gauge sample distances, the conclusions were made, and the recommended sample distance for this track geometry parameter is further elaborated.

2 Data collection and processing

Before measurements of tram tracks geometry, the tram network in the City of Osijek was divided into sections. This was performed in two steps. In the first step, the direction of tram traffic was taken into consideration. Then, an additional division was made due to the specific tracks layout, and organization of the lines. As a result, network was divided into 3 sections: Line L1: Zeleno polje–Višnjevac–Zeleno Polje; Line L2A: A.Starčevića–Mačkamama–A. Starčevića; Line L2B: Bikara–Mačkamama. Lines L1 and L2A are part of the double-track tram network, while L2B is part of the single-track tram network with passing loops at tram stops.

Measurements were carried out in November 2016 by manually operated trolley TEC-1000 (GRAW product) that meets the requirements of the European Standard EN 13848-4 [8]. Measuring elements of the trolley include inductive linear motion sensors and a data logger [9].

Figure 1 The TEC-1000 trolley

Collected track gauge values are expressed as relative values in relation to the normal track width, in this case, 1,000 mm, i.e. as gauge deviations. The measurements were recorded with a sampling distance of a 1-meter. Data collected along 27,520 measurement points was georeferenced along track sections Line L1, Line L2A, and Line L2B and structured into a single database.

The geometry quality assessment is based on track geometry deviations or irregularities. There are around ten statistics, called track quality indices (TQI), adopted throughout the world to assess the track quality of a track segment. The main difference between them is the base on which TQI is calculated, as standard deviation, an average value, or weighted value over a track segment [10]. According to the results, TQI can be sort into two main categories: (1) objective or single-track quality indices, which are expressed separately for each geometry parameter, and (2) artificial or combined track quality indices, which try a different combination of track geometry parameters [11]. In addition to different approaches, TQIs are expressed for different track segment lengths, usually over 3–25 m, 25–70, and 70–200 m long segments [3].

For this research, in accordance with the European Standard EN 13848-1, track sections were segmented into 200-meter-long segments. As a result of this segmentation process, the tram network in the City of Osijek was divided into 140 segments. In Figure 2. track gauge deviations are displayed for each segmented section,

The track gauge deviation value ranges from minimum -10,8 to maximum +24,0 millimetres. Although the track gauge deviation values on most segments range between 0 and 10 millimetres, there are certain segments where the track gauge deviation value is around or above 10 mm.

Overall, the average track geometry deviation value is 4,9 mm with a standard deviation of 3,3 and a coefficient of variation of 0,3 %. The median value is 4,1 mm. The frequency of the track gauge deviation value is shown in Figure 3.

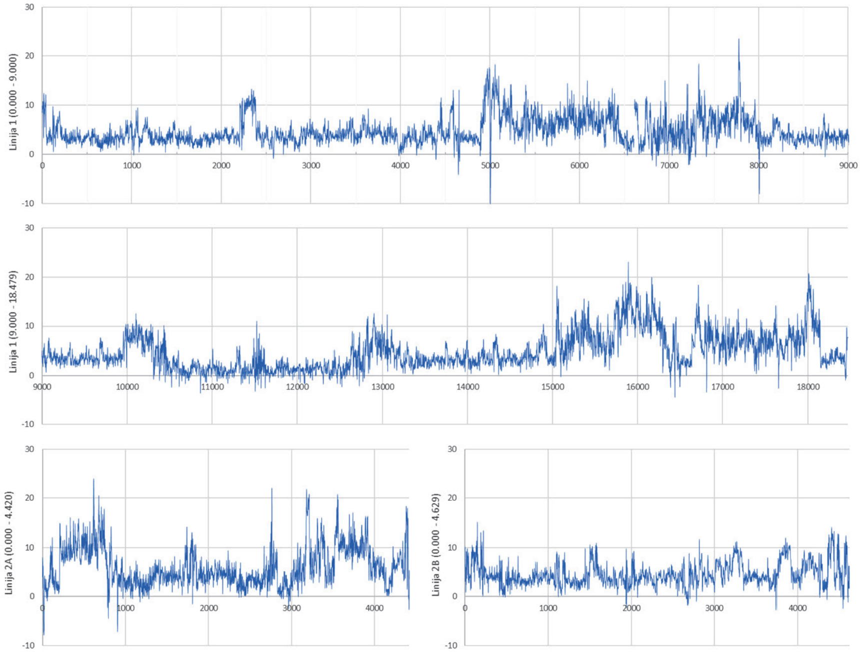

Figure 2 Track gauge deviations diagram, segmented, by sections

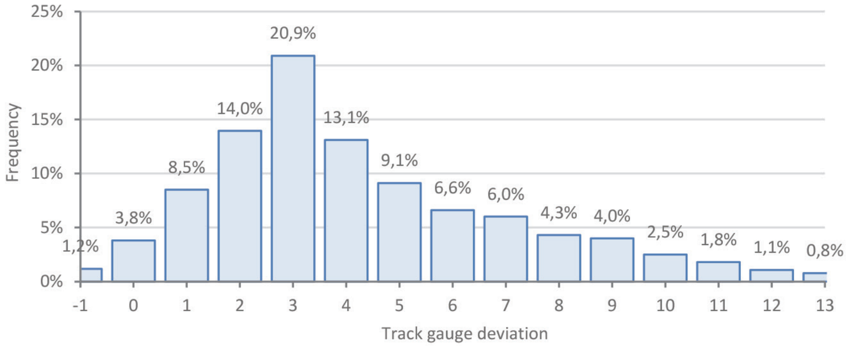

Figure 3 The frequency of the track gauge deviation value.

3 Track gauge data analysis

Track gauge deviation analysis was carried out for 200-meter-long segments using different gauge deviation sampling distances; 1, 2, 5, 10 15, 18, and 25 meters. A sampling distance of 1 meter represents the benchmark sampling distance. A bigger sampling distance means a smaller number of samples in a single 200-meter-long segment. For example, a sampling distance of 5 meters means that for each 200-meter-long segment there are 40 track gauge deviation values.

The analysis included calculation of track gauge deviation average values, standard deviation, and coefficient of variation for each 200-meter-long segment and different sampling distances. A linear regression analysis was then conducted to determine the level of correlation between and benchmark values calculated for sampling distance of 1 meter and values calculated for sample distances of 2, 5, 10 15, 18, and 25 meters. For each measure and sampling distance, correlation coefficient (r), coefficient of determination (R^2), and root-mean-square error (RMSE) were calculated.

The correlation coefficient is a statistical measure of the strength of the relationship between two variables and ranges from -1 to +1, where value +1 indicates that there is a positive relation, value -1 indicates that there is a negative relation, and value 0 means that there is no relation between two variables. Calculated correlation coefficients larger than 0.879 are showing that there is a positive relationship between two variables in all cases, but the relation is weakening with the increase in the sampling distance.

The goodness of fit between two variables is expressed with the coefficient of determination, which ranges from 0 to 1, where value 0 indicates that there is no relation between two variables and value 1 indicates the strongest possible relation of the variables. An increase in the sampling distance from 1 to 25 meters has a small effect on a change of the track gauge deviation average values but has a significant effect on the other two measures, track gauge deviation standard deviation and coefficient of variation. For example, the coefficient of determination calculated for the track gauge deviation average values changes from 0.997 for a 5-meter sampling distance to 0.988 for a 10-meter sampling distance. For the same change in a sampling distance, the coefficient of determination calculated for the track gauge deviation standard deviation values changes from 0.982 to 0.863 while the coefficient of determination calculated for the track gauge deviation coefficient of variation values changes from 0.982 to 0.862.

RMSE indicates how close the values calculated for a benchmark sampling distance are to the values calculated for increased sampling distance, where a value of 0 would indicate a perfect fit. An increase in the sampling distance from 1 to 25 meters has a significant effect on a change of all three measures, the track gauge deviation average values, standard deviation, and coefficient of variation. For a change in a sampling distance from 5-meters to 10-meters the RMSE calculated for the track gauge deviation average values changes from 0.142 to 0.263, the RMSE calculated for the track gauge deviation standard deviation values changes from 0.139 to 0.386, and the RMSE calculated for the track gauge deviation coefficient of variation values changes from 0.014 to 0.038. The results of linear regression analysis are presented in Table 1.

Table 1 A linear regression analysis result

Measure 2 m		**A sample distance**					
		5 m	**10 m**	**15 m**	**18 m**	**25 m**	
Average	r	1.000	0.998	0.994	0.988	0.985	0.971
	R2	1.000	0.997	0.988	0.976	0.970	0.943
	RMSE	0.030	0.142	0.263	0.381	0.426	0.571
Standard Deviation	r	0.999	0.991	0.929	0.946	0.908	0.879
	R2	0.998	0.982	0.863	0.896	0.825	0.774
	RMSE	0.044	0.139	0.386	0.387	0.519	0.548
Coefficient of Variation	r	0.999	0.991	0.929	0.946	0.908	0.879
	R2	0.998	0.982	0.862	0.895	0.824	0.772
	RMSE	0.004	0.014	0.038	0.038	0.052	0.054

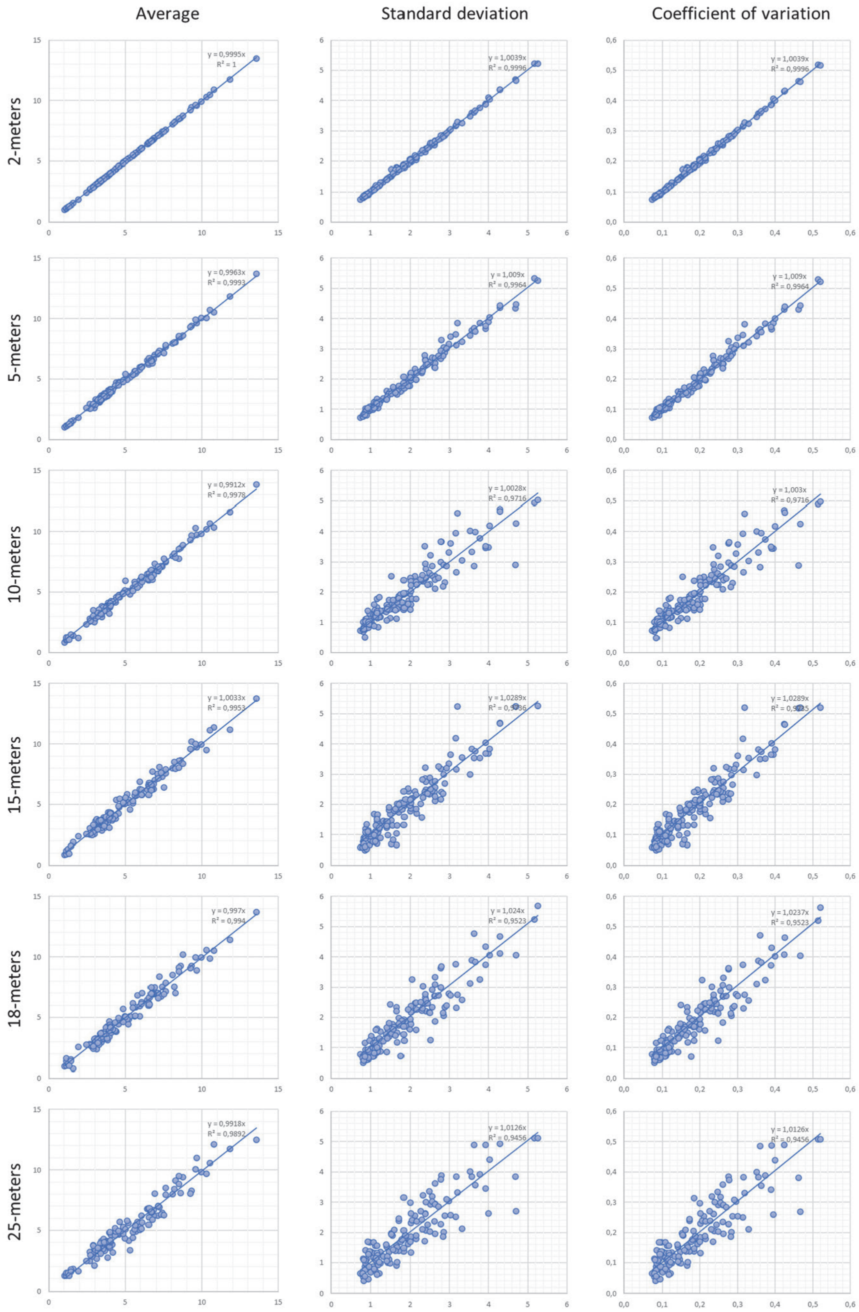

Figure 4 A linear regression analysis scatterplots

Scatterplots for the track gauge deviation average values, standard deviation, and coefficient of variation calculated for each segment with different sample distances are presented in Figure 4. The abscissa shows the measuring values calculated for each segment and benchmark 1-meter sampling distance while the ordinate shows the measuring values calculated for each segment with a larger sample distance.

As expected, an increase in the sampling distance, in relation to the benchmark 1-meter sampling distance, increases the dispersion of the sample data and therefore an error in the track gauge deviation analysis.

4 Conclusion

Decisions on track reconstruction are very often determined based on the track geometry irregularities, the key parameters in track geometry quality assessment. Track irregularities are usually measured with track-recording vehicles. Small urban railway system administrators usually do not have such sophisticated and expensive track maintenance machines, but the recording of the track geometry is carried out manually using a measuring trolley or a measuring rod. Such measurements are time-consuming and can lead to traffic disruptions.

The possibility of tram track geometry monitoring scope optimization presented in this paper was examined on the sample of the Osijek tram network gauge deviation values. The goal was to determine how to increase the monitoring frequency on the sections with a higher degree of track degradation by reducing the number of values measured along the tracks, ie by increasing the sampling distance, and still maintain the desired monitoring accuracy.

The result of the linear regression analysis shows that by increasing a sampling distance to 5 meters on a 200-meter-long segment it is possible to maintain the desired accuracy of the track gauge deviation value and therefore to optimise track gauge monitoring scope on small urban railway systems.

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