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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CETRA[2018]
5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

TITLE
Road and Rail Infrastructure V, Proceedings of the Conference CETRA 2018

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

ISBN
978-953-8168-25-3

DOI
10.5592/CO/CETRA.2018

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY
"Tiskara Zelina", May 2018

COPIES
500

Zagreb, May 2018.

Proceedings of the
5th International Conference on Road and Rail Infrastructures – CETRA 2018
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CETRA2018 17–19 May 2018, Zadar, Croatia
5th International Conference on Road and Rail Infrastructure

REHABILITATION OF RAILWAY TRACK QUALITY IN CONDITIONS OF THE SLOVAK REPUBLIC

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Abstract

The railway infrastructure is an extensive transport system in every country. Its parts and principles of operation are complex and varied and therefore it is not easy to establish a proper maintenance system strategy. Throughout the sys-tem, the railway track is the focal point of the infrastructure – the part in direct contact with rolling stock, which must provide a stable and safe system for movement and other railway operations. After the construction has been put into operation, the railway infrastructure manager performs diagnostic activities at a prescribed interval. They include collecting, evaluating and comparing data of construction state and its development. The aim is to identify and predict the degradation quality of the construction and to establish a quality rehabilitation strategy to bring it closer to the quality at the start of the service lifecycle. The paper deals with the theory and results of practical methods of diagnostics of the railway track quality in the Slovak Republic. It also identifies the conditions for the creation of predictive models of quality degradation from the diagnostics data and their influence on the determination of the construction maintenance strategy.

Keywords: track geometry, diagnostics, quality, predictive models, rehabilitation

1 Quality of railway track

The satisfactory state of the railway track construction can be characterized by the durability of its quality and operational reliability. The design is believed to be reliable if it fulfils the specified function under the operating conditions for a specific period. The development of the construction quality, described by the probability of error, characterizes the risk of error. The curve of the function of the risk degree in the lifetime of the railroad structure has the shape of a bathtub ("bathtub curve" [1]). In the initial part of structure life, errors are a result of struc-ture creep, insufficient structural resistance or built-in material and a failure to comply with production or construction technology. The error rate gradually decreases with time. In the middle of construction life, the risk of error is approx-imately constant. At the end of life, the error risk rate is increasing. It is influ-enced by the operational state of the structure and its parts: age of construction, wear due to traffic and nontraffic load, insufficient or incorrect corrective inter-ventions. However, a specific type of corrective action is appropriate for each period of life:

1) Maintenance (preventive) performed after completion of the construction or complex rehabilitation. Preventive actions to eliminate deficiencies arising from defective material or inconvenient state of construction are included. Their purpose is to prevent premature degradation of the design quality.
2) Repair work performed periodically to restore the defined design quality. It includes repair of track geometry and replacement of worn or faulty parts of the structure. The purpose is to ensure operational safety and to slow the deterioration of the construction.

3) Rehabilitation carried out when a technically or economically appropriate repair method cannot be applied. In this case, a complete replacement of the structure or its parts is done to restore or achieve the required quality.

Defining the railroad quality development is based on the characteristic behav-iour of the structure during its service life and the cost assessment. The planned service life of a railroad tends to be very long (depending on the construction and the operating environment it is 25 to 50 years). If in the initial part of the lifetime inadequate (not preventive) repair activities are performed to minimize operating costs, the structure reacts to it by irreversible shortening of the stability period of the track geometry quality. The errors repaired in the intervention limit are then transferred to other parts of the life cycle, (‚track memory phenome-non'). Meeting the requirements of operational quality and economic efficiency of the railroad management, operation and maintenance raises questions re-lated to the technical importance of high railway track quality. We need to de-termine to what extent it is economically optimal and what factors represent a railroad of sufficient quality. After defining the correct dimensions representing the quality of the structure, it is necessary to develop a model of its degradation reflecting the actual operating conditions of the structure. Such a model can serve as a basis for assessing the impact of different maintenance strategies on the railroad life.
The behaviour of the construction, applied in the quality assessment, is repre-sented in many railway companies by a single value of the quality index for the designated track section. The determination of the quality index of a verified section is affected by the structure of the data entering the assessment process (diagnostic data). By its representativeness, the data also influences the predic-tion accuracy of the future state of the construction. The primary type of infor-mation is usually information on the state of track geometry. In the more ad-vanced track diagnostic systems, information on the rail profile geometry, me-chanical properties of the structure (stiffness) and properties of rail vehicles and their response to the railroad state is added. In an optimal environment, the structure is put into operation in an excellent condition in which the quality indi-cators reach minimum degradation values. The objective of the railway infra-structure manager is to maintain such a state for the longest operating time during which he performs the minimum routine maintenance activities at the acceptably slow quality degradation of track geometry and structural elements.

2 Diagnostic data recording – detection of track quality

In the field of diagnostics of the railway, it is important to define the structures, their parts or parameters, which are crucial for the railway operation safety. The up-to-date information about them, combined with "historical" data in the results of previous diagnostic and repair actions, provide a basis for predicting the future state of construction and planning future repair actions. The creation of models of quality degradation and prediction of its future devel-opment produce one of the groups of outputs of scientific research activity at the Department of Railway Engineering and Track Management of the Faculty of Civil Engineering of the University of Zilina. The data for these models is ob-tained experimentally, except the ones based on the application of geodetic methods, by determining the operational railroad quality by a continuous meth-od using a diagnostic tool with continuous scanning and recording of measured values – a track geometry trolley KRAB™-Light. The methods, measured track geometry quantities, their standard tolerances, values and measurement as-sessment are implemented according to the legislative documents of Slovak Railways (ZSR) [3] and [4].
The quality assessment of the track geometry is, according to the valid legisla-tion, aimed at the occurrence of local errors of: track gauge (RK), track gauge change (ZR), track elevation (PK), right/left rail (VP, VL) top level (VK), the right/left rail (SP, SL) alignment (SK), rail twist to 3.0 m, 6.0 m and 12.0 m base ($ZK_{3.0}$, $ZK_{6.0}$, $ZK_{12.0}$) and section quality number QN with support of standard tolerance SDV of quantities: SK, RK, PK, VK. These indicators currently repre-sent

the track geometry quality monitored by the trolleys for measuring track geometry under ZSR conditions. The assessment of the SK, RK, PK, VK by the quality marks QM, the overall mark of the quality OMQ of the assessed section and the tamping mark TM in the ZSR environment is considered perspective but at present only complementary.
At present, the verification of the operational quality focuses on track geometry monitoring at three experimental sections (tunnel Turecky vrch – experimental section No. 1, Bratislava tunnel No. 1 – experimental section No. 2 and the ex-perimental section No. 3 – Trencin Bridge). In the following text, the data ob-tained by diagnostics and assessment of the experimental section No. 1, which is the tunnel section Turecký vrch, is used. This section has been monitored since 2012, with approximately 6-month periodicity (MSO and PO1 to PO10 measurements) and consists of four sub-sections. The results achieved so far have been published, e.g. in [5] and [6].
The first track geometry measurement in the respective experimental section in the SZ4 speed zone (120 ‹ V ≤ 160 km/h) was performed as a measurement for acceptance of construction work on the track and in the switches, with the application of new material (MSO level). The MSO is characterized by the val-ues the construction tolerance limits or values of the geometric quality of the track. Other measurements are defined as operating diagnostics (at AL, IL, IAL levels), where operating and limit operating deviations, or the track geometry values define the track geometry quality in AL (alert limit), IL (intervention limit) and IAL (immediate action limit).

3 Assessment and analysis of railway track diagnostic data

The assessment and analysis of data representing the degradation of the rail-road quality influence the decisions of the infrastructure manager on various aspects. These include the optimal intervals of the current state of construction, residual lifetime estimates, life cycle costing of the entire structure or its compo-nents and predicting the appropriate time for corrective interventions. Current ZSR strategies of repair work are based on local errors in the track geometry, determined by the measurement interpretation. The railway infrastructure man-ager plans and implements their (immediate) removal by methods equivalent to detected local errors. However, the track geometry quality assessment also contains other indicators that will help them optimize current and create long-term repair strategies. To capture the trend of quality degradation of the struc-ture and to plan the repair work, we can use models of degradation and predic-tions of future quality development that have been created and assessed for a specific track section (experimental section No. 1) from the diagnostic data of this experimental section.
The models work with available diagnostic data of track geometry and use re-gression and correlation tools of generally available software (MS Excel©). The legislative document [7] states the determining quantities for maintaining no-failure operation and safety of the railway track, as the track alignment and top of the line position of the track (rail top level): SK (SL, SP), or VK (VL, VP). [8] contains an elaborated design and assessment of several methods of predict-ing the quality development of these determining quantities.
The track geometry evaluation of quality indicators is, concerning the continuity of development interrupted by repairs, focused on the period after their imple-mentation, i.e. operating measurements PO5 to PO9. The models are comple-mented by a PO10 data set that represents the track geometry quality after a corrective intervention performed on the day of measurement implementation (16th or 17th October 2017). The diagnostic data pooling for modelling respects the segmentation principle of the monitored sections of the track geometry qual-ity verification, as prescribed in [3] and [4]. These documents specify that the maximum length of the segment is 1 000 m [4]; and the decisive technical factor is the parameters of the longitudinal position of the track (the direct sec-tion/transition curve or arc), conditioned by using the RK value levels defined in [3]. Models (except the first model in the list below), are constructed using mathe-matical statistics, its regression and correlation analysis tools,

with the support of data diagnostics of the previously conducted measurements of the experimental section No. 1. In [8] they show the dependencies of data group values on the measuring sites or on the time of measurement, or interdependence between two data sets. They also define the interdependent relationships of respective quantities or the dependencies of their limit values and time, where the quality indicator achieves the standard value and they represent the theoretically expected de-velopment of:

- the section course of the measured deviation of the determining quantity (SL/x, SP/x, VL/x and VP/x),
- the time course of the maximum deviation value of the determining quanti-ty ($\Delta|SL, SP|_{day}/t$ and $\Delta|VL, VP|_{day}/t$),
- the time course of the average value of the change of deviation of the de-termining quantity ($|SL, SP|_{max}/t$ and $|VL, VP|_{max}/t$) (Fig. 1, 2),

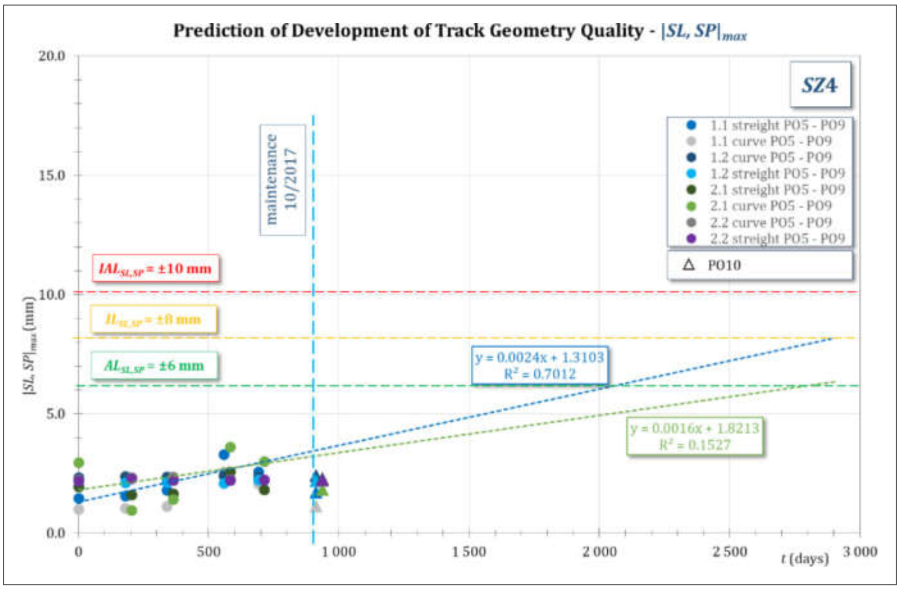

Figure 1 Experimental section No. 1 – graphical representation of relation-ships of correlation and regression analysis $|SL, SP|_{max}/t$

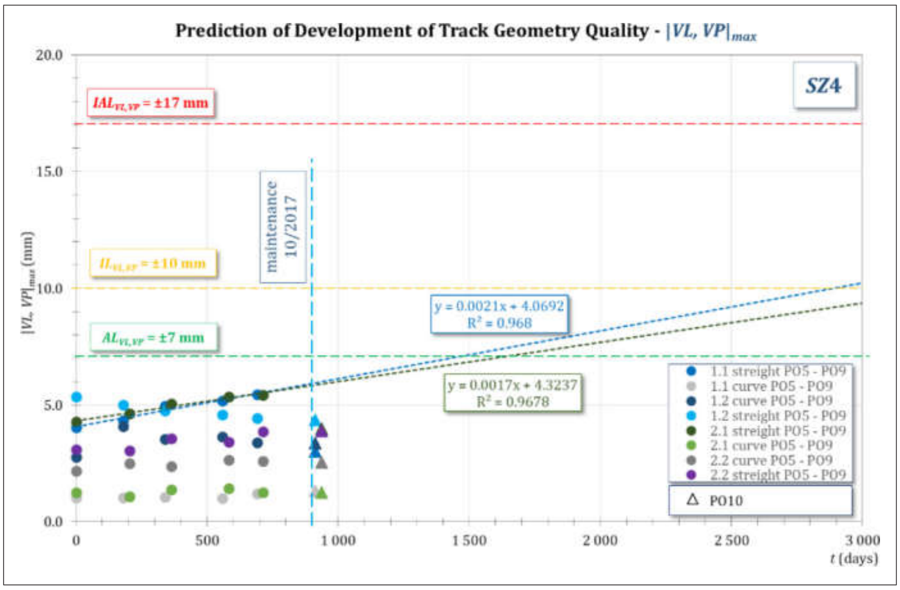

Figure 2 Experimental section No. 1 – graphical representation of relation-ships of correlation and regression analysis $|VL, VP|_{max}/t$

• the mutual relationship between the maximum deviation value and the standard deviation of the determining quantity ($|SL, SP|_{max}/SDV_{SK}$ and $|VL, VP|_{max}/SDV_{VK}$),
• the time course of the standard deviation of the determining quantity (SDV_{SK}/t and SDV_{VK}/t),
• the time course of the section quality number (QN/t) (Fig. 3).

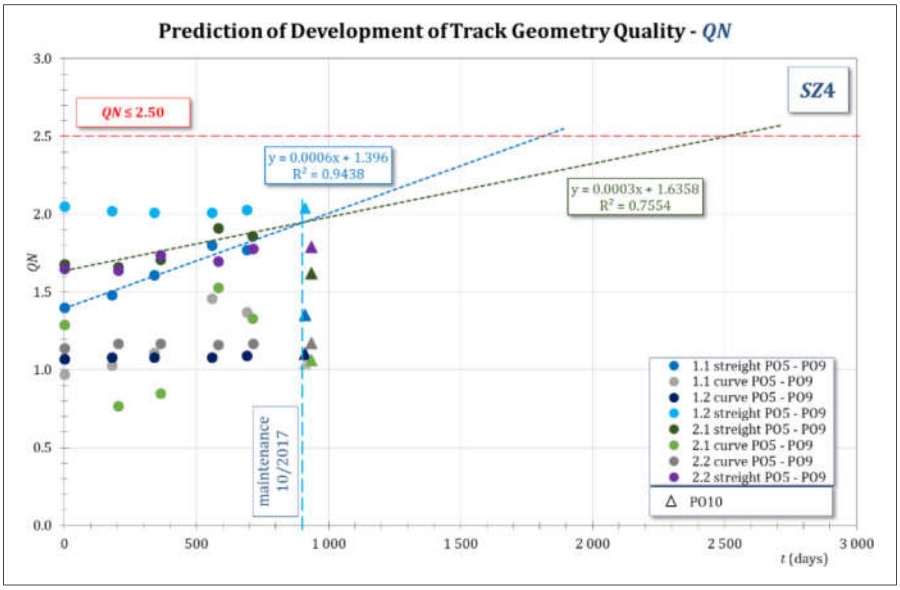

Figure 3 Experimental section No. 1 – graphical representation of relation-ships of correlation and regression analysis QN/t

4 Selection of a model for rehabilitation of track quality

A representative model of degradation and rehabilitation of the structure quality, regardless of the diagnostic area of interest is based on the analysis of a large amount of data according to an effective number of aspects. The database of diagnostic data and construction information should be sufficiently extensive. It should include the “historical data”, to capture all types of information present-ing the past and current state of construction. Moreover, it requires information affecting its future development. At the same time, the database should have a form that enables to search for structural errors and deficiencies and identify their causes. The goal is to make the best possible decision on the method and time of rehabilitation of the construction quality. .
Table 1 shows a matrix of input diagnostic data and a description of the maintenance (M), repair (R) and reconstruction (RN) activities. These activities represent rehabilitation models by the infrastructure manager. The matrix is designed to help select the rehabilitation model. The marked diagnostic data is crucial for the relevant model. If the set limit values in the presented set of diag-nostic data are exceeded and result in construction errors, the infrastructure manager can select a relevant rehabilitation model to remove a whole group of these errors. It is appropriate to specify the decision-making process within the operational application by other decision-making rules. Important aspects of this process include the significance of the diagnostic data for the relevant activity of quality rehabilitation, and the standardized (standard or limit) value of the quality indi-cator. The parametric data of the repair work: location, source characteristics (material, machinery and equipment, workers, time) are also highly significant here.

Table 1 Decision-making process of selecting the quality rehabilitation mod-el: a matrix of input data [8]

Maintenance and renewal / Diagnostics data of railway track quality (track geometry, structural elements of railway grid and basic information about track)	M: repair of gauge	M: repair of longitudinal position	M: repair of directional position	M: completing of railway grid elements	M: repair of railway grid elements	M: replacement of railway grid elements	M: screw of fastening	M: repair of rail joints	M: repair of welded rail	M: completing of ballast bed material	M: cleaning of ballast bed material	M: correction of width of switch groove	M: maintenance of switch blades and crossings	R: repair of geometry	R: repair of ballast bed	R: replacement of sleepers	R: replacement of rails	R: rail reprofiling	R: repairing of switch blades and crossings	RN: replacement of track panels	RN: assembling of track grid in track centre line	RN: replacement of track grid in switch
Code of quality of spatial position of track		●	●											●						●	●	●
Track quality index (SDV, MQ, TMQ, MT, QN)	●	●	●					●						●						●	●	●
Number of local errors																						
(overrun of level AL, IL or IAL)	●	●	●					●						●						●	●	●
Location of track geometry errors	●	●	●					●						●						●	●	●
Proportion of sections with local error																						
in total length of evaluated section	●	●	●					●						●						●	●	●
Graphical profile of track geometry errors	●	●	●					●						●						●	●	●
Rails – type, year of installation							●	●	●			●	●	●			●	●	●	●	●	●
Number of rail failures by category (A – D)							●	●	●			●	●	●			●	●	●	●	●	●
Percentage of rails with failures (length)							●		●				●	●			●	●	●	●	●	●
Percentage of rails with abrasion (length)						●		●					●	●			●	●	●	●	●	●
Number of errors: rails with abrasion						●		●						●			●	●		●	●	
Number of errors: switch blades																						
and crossings with abrasion						●							●	●			●	●	●			●
Abrasion value of rails / switch blades						●		●				●	●	●			●	●	●	●	●	●
Number of errors of rail joints								●						●						●	●	●
Welded rail – clamping temperature									●					●	●	●	●			●	●	●
Number of errors of rail weld geometry														●				●		●	●	●
SDV of rail microgeometry																		●		●	●	●
Sleepers or slab track–type, year of installation	●			●	●	●								●		●				●	●	●
Percentage of damaged sleepers																						
with impact on fastening functionality	●			●	●	●								●		●				●	●	●
Percentage of damaged sleepers																						
without impact on fastening functionality	●			●	●	●								●		●				●	●	●
Length of sections with cumulating																						
of damaged sleepers	●			●	●	●								●		●				●	●	●
Fastening – type, year of installation	●			●	●	●	●	●						●	●	●	●			●	●	●
Percentage of dysfunctional fastening	●			●	●	●	●	●						●	●	●	●			●	●	●
Percentage of missing fastening	●			●	●	●	●	●						●	●	●	●			●	●	●
Length of sections with cumulating																						
of dysfunctional/missing fastening	●			●	●	●	●	●						●	●	●	●			●	●	●
Ballast bed – type, year of installation		●	●							●	●			●	●	●				●	●	●
Percentage of the polluted ballast bed		●	●							●	●			●	●	●				●	●	●
Percentage of whole capacity of ballast bed		●	●							●	●			●	●	●				●	●	●

5 Conclusion

In Slovak conditions, the monitoring of track geometry quality is the basic method for monitoring and displaying the track quality as a whole.
The decrease of the construction quality in its degradation phase is a natural response to two types of load. The primary load is the load of the means of railway transport and maintenance (traffic load, representing the physical load of the structure). The secondary load is the load of the climatic impacts represented by low and high temperatures, or their changes, due to wind and precipitation (non-traffic load).
The paper shows the results of more than five years of data collection representing the track geometry quality, whose degradation is a response to the traffic load. The collected data of representative quality indicators serve to create degradation predictive models. The models and understanding of the causes of construction behavior lead to the identification of its weaknesses. This will enable the railway manager to predict the quality development and timely plan the quality rehabilitation activities. To support the decision-making process and to select a suitable rehabilitation activity, the matrix of diagnostic data and repair work is also used. In the next period, the authors will expand the range of diagnostic data. The data will be used to refine the degradation prediction models of track geometry quality of the experimental tracks.

Acknowledgments

The paper contains results of the grant VEGA 1/0275/17 Application of numeri-cal methods to define the changes of geometrical track position.

References

[1] Lyngby, N., Hokstad, P., Vatn, J.: RAMS Management of Railway Track. In Book: Handbook of Performability Engineering. [on-line]. London: Springer-Verlag London Limited, 2008. pp.1123-1145. DOI: 10.1007/978-1-84800-131-2_68.

[2] Esveld, C.: Modern Railway Track. [electronic source]. Digital Edition. Ver-sion 3.8. Zaltbommel: MRT-Productions, a subsidiary of ECS, 2016. ISBN 978-1-326-05172-3.

[3] STN 73 6360-2: 2015: Railway Applications. Track. Part 2: Acceptance of Con-struction Works, Maintenance Works and Assessment of Service Condition Track Gauges 1 435 mm.

[4] ZSR Service Manual SR 103-7 (TS) Measurement and Evaluation of Track Ge-ometry Track Gauge 1 435 mm and 1 520 mm by Measuring Trolley KRAB (in Slo-vak). Validity since 1. 1. 2017.

[5] Ižvolt, L., Šestakova, J., Šmalo, M.: Analysis of Results of Monitoring and Pre-diction of Quality Development of Ballasted and Ballastless Track Superstructure and its Transition Areas. In Communications: Scientific Letters of the University of Zilina. ISSN 1335-4205, 2016. vol. 18, no. 4, pp. 19-29, 2016.

[6] Šmalo, M.: Diagnostics of Track Quality of Ballastless Track and Transition Areas in Vicinity of Portals of Tunnel Turecky vrch. In Civil and Environmental Engi-neering: Scientific-technical Journal. ISSN 1336-5835, Vol. 12, No. 1, pp. 2-12, 2016.

[7] STN EN 13848-6 (73 6315): 2014: Railway Applications – Track – Track Geometry Quality – Part 6: Characterisation of Track Geometry Quality.

[8] Šestáková, J.: Diagnostics of Operational Quality of Railway Track and its Influence on Renewal Work Planning, Habilitation thesis. Zilina, University of Zilina, 2017.