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Track geometry quality assessments for turnouts

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ABSTRACT

Turnouts are necessary, frequent and cost intensive. Despite the railway sector's focus on automation, the condition assessment of turnouts is still mostly done manually by responsible staff inspecting the turnout. While system's safety is guaranteed by this approach, drawbacks are high costs, subjectivity of assessments and a missing opportunity of prognoses. Most importantly, we will not expect to have the workforce for this regime in future years. By assisting responsible staff with data-based quality assessments, save and time optimised inspection can also be guaranteed with labour force reductions. For providing this, we use data from the track recording car, apply a post positioning procedure and calculate quality indices describing track geometry quality of turnouts in an objective way. The visualisation of these indices over time lead to data sheets which can be used by the responsible staff for maintenance planning. Additionally, the indices build the basis for predictive maintenance regimes for turnouts and open several possibilities for practical and academic enhancements regarding asset management of turnouts.

1. Introduction

Turnouts are an essential part of the railway infrastructure. For railway operation, turnouts offer the possibility to change track while the train is moving and thus allow a certain operational flexibility in a basically rigid railway system. This not only enables efficient use of the infrastructure for pre-planned operations, but also short-term flexibility in the event of disruptions within the system. Especially the latter leads to the fact that in all mixed traffic networks a certain number of turnouts is installed, often currently not absolutely necessary, but operationally desired or required. In Austria, 13,285 turnouts are integrated into a network of a length of 9759 km [1]. This results into 1.36 turnouts per track kilometre (0.9 for the main network). For the cumulated network of EU27 countries, this factor is estimated to 1 turnout/track kilometre, which results into 300,000 turnouts within these networks [2].

The technical complexity, operational importance and intense focus on safety lead to turnouts being a very expensive asset in the railway system. Network-wide life cycle cost (LCC) evaluations for Austria show a factor of 7 between LCC of one metre turnout, compared to the open track [3]. This factor increases to 13 when it comes to maintenance costs. According to *Cornish*, the cost of turnouts in the UK in 2011/2012 was £200 million for maintenance and £189 million for renewal [4]. This equals to 24% of the total track maintenance budget while only accounting for 5% of network mileage. The results of a questionnaire designed by Graz University of Technology and answered by infrastructure managers in several European countries also reflect the high cost of turnouts. According to the answers to the question "How high are maintenance costs of turnouts in comparison to open track? Please enter a rate.", 20 to 50% of maintenance budget is reserved for turnouts. These rates can be understood as a rough guess; however, all answers point to the high maintenance costs of turnouts.

Alongside renewal and maintenance, turnout inspection expenses are another cost factor [5]. For the open track, these costs could be reduced through the use of measuring cars in recent decades. However, manual inspection by track personnel is still the predominant form of turnout inspection [6]. This goes along with some advantages: Qualified personnel can ensure a safe turnout condition by manual measurement and assess the overall condition at the same time. On the other hand, there are some disadvantages: As manual inspection is time and labour intensive, high costs arise [7]. Tracks have to be closed or workers are within the danger zone [8]. As the local measurements are carried out on the unloaded turnout, the measured parameters cannot be used for the prognosis of future conditions. In sense of life cycle management, such an inspection regime is insufficient. The most urgent problem, though, is that a lot of qualified personnel is needed for inspecting each turnout within the network. At least in Austria, this becomes an ever-growing

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problem, as train numbers are rising but the number of track workers are expected to shrink.

A solution to several of the problems mentioned is a predictive maintenance scheme based on measurement data [9], combined with LCC evaluations [10,11]. If condition assessments based on network-wide measurements work properly, manual inspection can be reduced. If condition predictions are also possible, this can lead to better maintenance planning in line with life cycle management. For open track, predictive maintenance led to significant reductions of life cycle costs in the last years [12,13]. However, a similar regime is not applicable for turnouts at the moment. Based on the current data situation, four main topics need to be addressed in order to achieve this goal: (1) Data positioning accuracy, (2) feasible row-data visualisation, (3) component-specific quality indices, and (4) economic-based intervention levels.

As turnouts are limited in length, positioning accuracies feasible for open track is insufficient for turnouts [14]. However, it is also possible to use the data from a track recording car by applying a suitable repositioning procedure. *Fellinger* has developed a post-positioning procedure for the data of the Austrian measuring car, which is also used for this work [15]. A positioning accuracy of 25 cm is achieved, both relatively (between measurement runs) and absolutely (asset localisation). This accuracy makes meaningful raw data visualisations and time series evaluations possible.

The limited length of turnouts also hinders the use of quality indices proven to be effective for open tracks. Typical influence lengths are 100 to 200 m here [16], which exceeds the expansion of standard turnouts. Quality assessments according to these indices would therefore lead to a mixed evaluation between open track and turnout, not fulfilling expectations. The use of sliding influence windows as shown in [16] can help a bit, but not solve this problem fully. For this reason, new quality indices for turnouts move into our research's focus. Such indices shall support track engineers and could be basis for predictive maintenance schemes for turnouts in a next step.

In this paper, the focus is on track geometry, which is one of the most important quality parameters for railway tracks and turnouts [17]. According to EU regulations [18], track geometry has to be restored if it falls below a certain level. This is done by levelling, lining and tamping, which is very well automated and therefore relatively inexpensive. However, as several tamping operations are required during the life cycle of a turnout, absolute costs of tamping account for a large part of the maintenance budget [13]. In addition to the significant costs of correcting poor track geometry, track geometry serves as an indicator of poor system behaviour [19]. If deterioration rates are high, either worn components or poor load distribution are responsible. On the question of optimal intervention levels for restoring the track geometry in order to achieve lowest LCC possible, a large number of studies is available for the open track [20–23]. However, these assessments are not suitable for turnouts, due to the missing specific quality indicators. A proposal for corresponding indicators is discussed here.

2. Methodology

The methodology is based on measurement data from the EM250, ÖBB's main track recording vehicle. Several systems are mounted on EM250. We use the longitudinal level signals (3–25 m) as the main indicator of track geometry. The rail surface signal and axle box acceleration measurements are included for the raw-data visualisation, as this brings additional information on system interactions. Details about the rail surface measurement system are available within a recent publication [24]. For the listed measurements, we rely on data from 2005 to 2021 enabling to work with time series. The horizontal level is in principle also available, but is not included in the assessment for three reasons. (1) The longitudinal level is the main factor in triggering tamping. (2) Longitudinal level and horizontal level are strongly correlated, so including one of the two measurements is a practical simplification of the evaluation. (3) As the horizontal level measurements are influenced by the optical level measurement, it is not entirely clear how reliable the measurement at the crossing nose is. As described in the introduction, the main problem in using data from a track recording car for the evaluation of turnouts is the positioning accuracy. Here, we use an algorithm based on *Fellinger*, slightly adopted [6]. In the applied method, the relative shifts between the measurement runs are determined by calculating the Euclidean distance between the signals for each possible relative displacement. The relative displacement with the smallest cumulative Euclidean distance is closest to synchronicity and is applied subsequently. Absolute positioning is done using a unique signal characteristic at the crossing nose. The adaptation does not refer to core principles of the algorithm, but only concerns an automation of the process. This is necessary for a time-efficient application. Details can be found in recent publications [6,24].

The case study carried out in the next chapters is based on a turnout installed in the ÖBB network. It is a curved turnout with a diverging radius of 1200 m. The superstructure consists of wooden sleepers and 54E2 rails, the turnout was installed in 1996. The daily load is approx. 70,000 gross-tonnes, with a permissible line speed of 160 km/h and mixed traffic.

2.1. Interactive raw-data visualisation

The output of the post-positioning process are measurement data with a relative and an absolute position accuracy of 25 cm (25 mm for rail surface). The relative position accuracy is essential for time series analysis. Absolute positioning accuracy makes it possible to pinpoint data to the real asset. Doing so, the signal characteristic of raw data can give relevant information on the condition of the analysed turnout. Therefore, the first step of data analysis is a meaningful visualisation of raw-data. Visualisations can be static or interactive. The latter has the advantage of providing more information in a compact form, which is the reason we chose an interactive visualisation. In Fig. 1 we give an example of what a meaningful data visualisation might look like.

The figure shows the rail in which the frog (crossing nose) is situated, represented by three different types of data. As only the frog-side of the turnout is shown, there is a second illustration for the other rail (side of the check rails). The black vertical lines are displaying the start and the end of the turnout. The turnout starts at the point where the tangent line of the branch line is parallel to the straight line and ends at the first sleeper with separated rail fasteners. At the moment, we are discussing whether to choose a different definition of the turnout end, i.e., the position of the last long sleeper. As already mentioned, the assignment of data to exact turnout positions is only possible through the positioning process, which also includes technical drawings of the turnout. Three types of data included are longitudinal level within D1 range (3–25 m), a filtered version of the rail surface signal and a derivative of the measuring car's axle box acceleration measurement. Unfortunately, the axle box accelerations are manipulated in the measuring car's internal system so that only relatively low frequencies are represented in the signal. A lot of information is lost in this process; however, some information can also be obtained from the processed signal. By clicking on the entries within the legend on the right-hand side of the application, measurement runs can be inserted into the visualisation window. For Fig. 1, three measurement runs are included (2020.5, 2020.8 and 2021,2). In addition, it is possible to fade in horizontal lines representing limit values. Here the alert threshold for the longitudinal level according to ÖBB regulations (and depending on the permissible speed of the respective turnout) is displayed. Likewise, intervention limits and immediate intervention limits can be shown.

From the data presented, various indications of the condition of the turnout, critical sections and maintenance measures carried out can be derived. Looking at the longitudinal level, two measurement runs in 2020 (green and blue) show very similar characteristics. As these measurements are carried out within three months, this is to be expected and

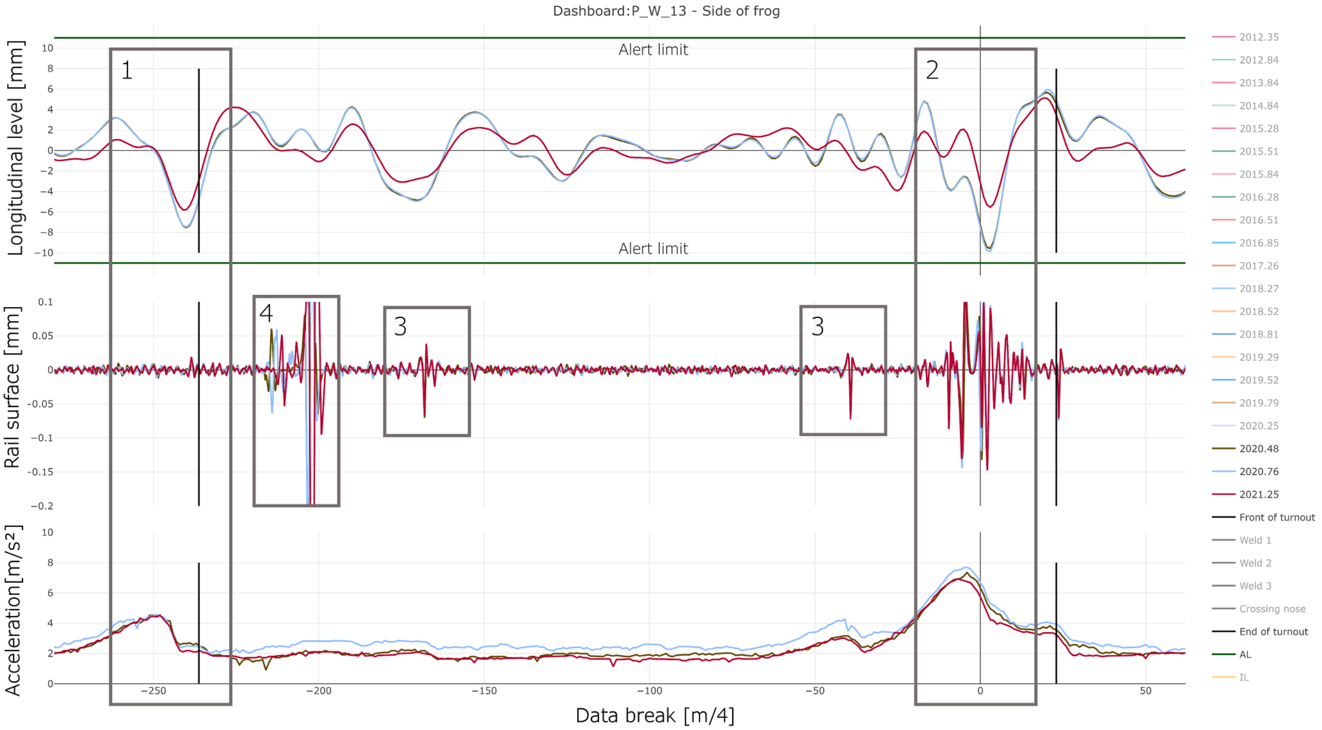


Fig. 1. Snapshot of an interactive raw data visualisation.

speaks for the quality of the data. The measurement in 2021 (red), on the other hand, shows a comprehensive improvement. This improvement is due to tamping carried out between the two measurement runs. Through the appropriate positioning and presentation of the measurement data, it is possible to evaluate the effectiveness of maintenance measures.

Another possibility is to identify specific problem areas of the turnout and subsequently monitor them. Immediately in front of the turnout (1), a significant isolated defect of track geometry can be seen in the longitudinal level signal. This defect also has a significant impact on the running behaviour of wheels, as a signal deflection can be seen within axle box acceleration. There are two typical reasons for a defect at this position: (1) Insulated rail joints are often located in front of a turnout. If the condition of the joint is poor, additional dynamic loads occur harming the ballast and thus causing isolated defects. (2) A change

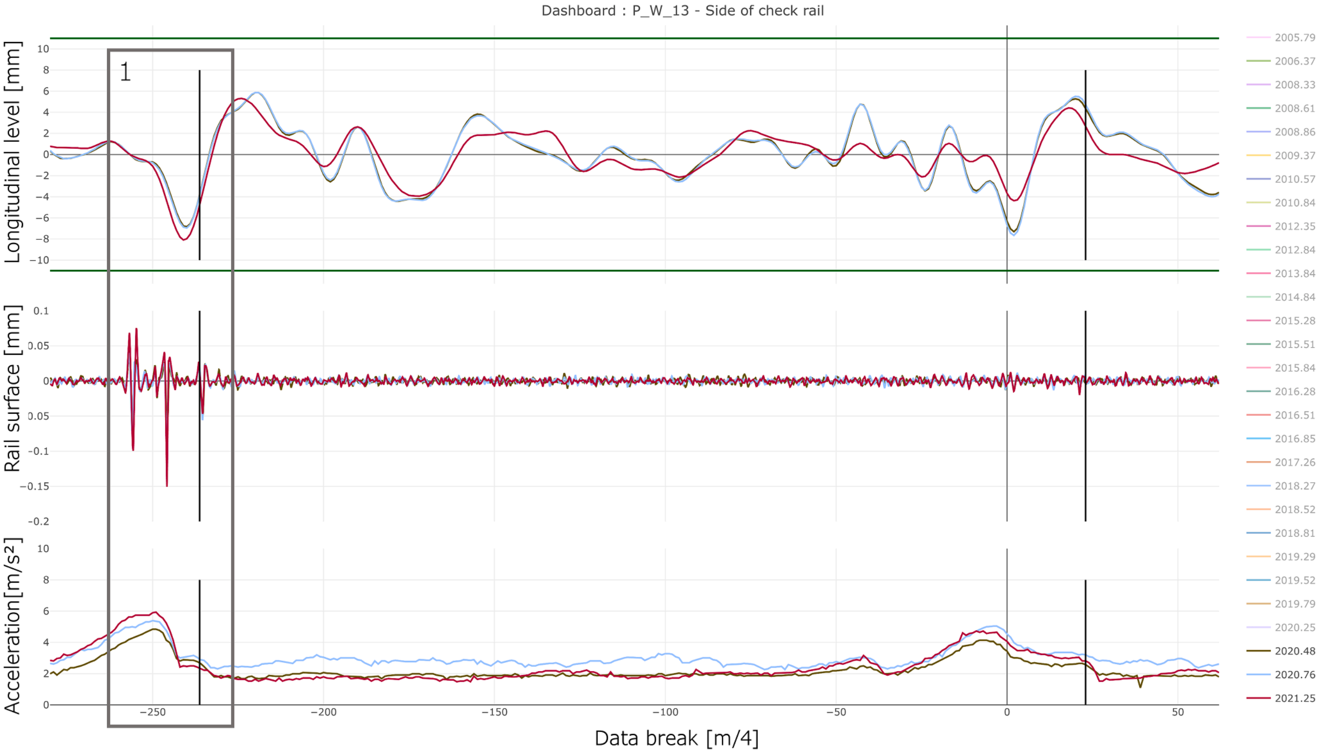


Fig. 2. Raw data visualisation – side of check rail.

in system stiffness due to other components of the superstructure (open track vs. turnout) leads to a weak point with higher dynamic loads. Since a worn insulated rail joint would be visible in the rail surface signal, we initially suspected an inhomogeneity of stiffness causing this defect. Upon analysis, however, it turns out that an insulated rail joint is the cause, but the one of the other rail. This can be seen in Fig. 2 only, where the affected rail is visualised.

Another interesting section is the frog area, marked with the number 2 (in Fig. 1). Since (fixed) crossings have a discontinuity due to a necessary gap, the load impacts in this section are high. The axle box acceleration signal can be used to determine vehicle reaction due to the given crossing geometry. A typical isolated defect of track geometry directly at the frog is one of the common consequences of high dynamic impact loads. Since the rail surface signal is a representative signal for the frog, we expect to obtain information about frog quality from a detailed analysis. Other publications will deal with this potential use of the signal. Besides the frog and nearby insulated rail joints, welding joints within the turnout can also influence the quality behaviour of the asset. Information about the geometric condition of the welded joint (mark 3) can be obtained from the rail surface signal. The signal output seen at mark 4 is a measurement error due to the transition from the stock rail to the switch rail and is therefore not relevant.

With appropriate raw data representation, an overview of the turnout's condition can be gained relatively quickly and critical areas can be identified. However, objective evaluations and condition prognosis are not possible; for this task, corresponding quality indicators must be developed first. For the open track, a differentiated analysis between isolated defect repair (on the basis of the longitudinal level itself) and Life Cycle Management-based (LCM-based) predictive planning of line tamping (sliding standard deviation of the longitudinal level with an influence length of 100 m) has proven to be the best option. We want to retain this approach, whereby both describing indices must be considered together, since in the turnout area an isolated defect of track geometry triggers tamping of the entire turnout. In the next subchapter, we deal with the calculation of an index that evaluates isolated defects in the turnout area. In the subsequent chapter, the LCM-based index for predictive maintenance planning will be discussed in detail.

2.2. *Utilisation rates for isolated defects of track geometry*

The raw signal of longitudinal level (D1) is the proven state of the art for the evaluation of track geometry and should also be used for evaluations in the turnout area. Since isolated defects are compared with intervention thresholds anyway, we choose a representation as utilisation rate here. According to EN 13848-5, three thresholds for track geometry have to be considered, alert limit (AL), intervention limit (IL), and immediate action limit (IAL). If AL is exceeded, intensified focus should be given to the respective defect, but no measure has to be set. For defects exceeding the intervention limit, maintenance should be carried out as soon as possible, but train operation is not affected. The most critical limit is the IAL. If defects reach this level, operation cannot continue, as immediate action have to be carried out for guaranteeing safety. One possibility though is to temporarily reduce the allowed line speed, as the absolute level of the limits are less strict for lower speeds. The EU standard also specifies values for every speed class. These specifications can be considered as minimum requirements for railway infrastructure within the European Union, with many infrastructure managers applying stricter limits in their national regulations. On the one hand, this is because the national regulations were written earlier than the EU standard. On the other hand, infrastructure managers aim to have time reserves in their maintenance regimes in order to plan and/or trigger the maintenance jobs. As our research is closely connected to data of ÖBB, we use the limits of the national regulation. Fig. 3 shows the calculated utilisation rates for one turnout, data since end 2005 is included.

For the calculation of the index, we set the most severe isolated defect within the turnout area in relation to a limit value. In principle, any limit value can be considered for the analysis, we worked with AL and IAL here. Since the calculation has been carried out for each measurement since mid-2005, a trend can be read off. In 2009, the utilisation rate for AL was above 100% (the AL was exceeded). Looking at the raw data, we see the location of the defect directly beneath the frog. In 2010, track geometry was restored within the frog area (also a frog exchange is suspected here) so that the utilisation rate drops. After maintaining the turnout in 2012 (tamping), the utilisation rate (AL) went down to 23% and since then increases steadily, interrupted by regular tamping actions in 2015 (2015.8) and 2021 (2021.2). In 2017 (2017.3), local maintenance for the insulated defect directly in front of the turnout took place, also reducing the utilisation rates. As the utilisation rate for IAL was never above 75%, safety – regarding track geometry - could always be guaranteed for the shown turnout.

2.3. *Cumulative track geometry index*

Since the aim of an LCM-based quality index for turnouts is to summarise the quality of the entire turnout within one index, the longitudinal level is unsuitable without further processing. For this, the signal must be reduced in its spatial extension (turnout length) to an index value. One simple approach would therefore be, to calculate the average of all measured values within the turnout. This approach though does not consider the fact that defects can spread both upwards and downwards and that the mean value therefore can be zero despite high amplitudes in both directions. Another approach is to use a (sliding) standard deviation of the longitudinal level as an index value, similar to the respective index of the open track. However, the influence length of 100 m does not allow for a sufficiently precise description, as areas outside the turnout are inevitably also evaluated for turnout lengths of less than 100 m. If the standard deviation of the longitudinal level is calculated over the entire turnout (influence length corresponds to turnout start to turnout end), the calculated index would give good

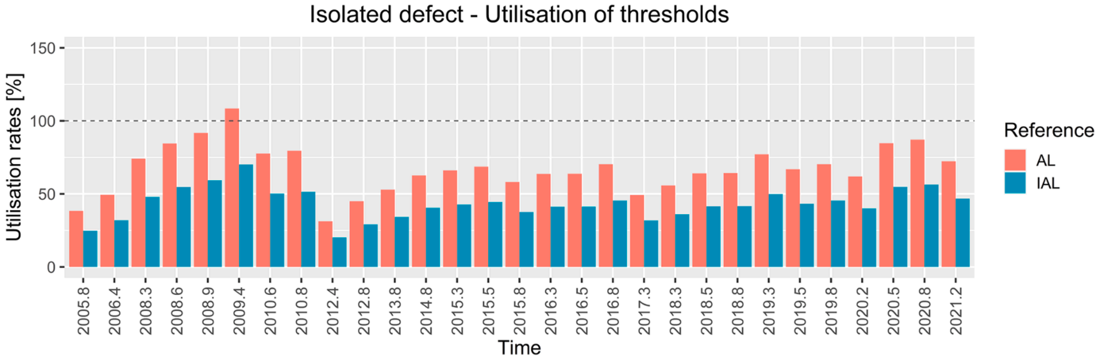


Fig. 3. Utilisation rates - isolated defect of track geometry within a turnout.

results for single turnouts, however, the index would be affected by the length of the turnout and therefore not be comparable with turnouts of other lengths. Uniform threshold values cannot be defined in this way, neither would it be possible to subset for the x% of the turnouts with the worst condition. It is conceivable to calculate the sliding standard deviation of the longitudinal level with a significantly reduced influence length and then derive a comparable index value by averaging all values within the turnout. However, from a mathematical point of view, the smallest possible influence length is limited: since the D1 range of the longitudinal level contains wave fractions of 3–25 m, the calculation of standard deviation with an influence length of less than 25 m yields mathematically incorrect results, since only portions of the failure characteristics are included in the calculation. Using Root Mean Square values (RMS) provides a remedy for this problem. This issue is dealt with in Fig. 4, which shows not only the standard deviation of track geometry but also RMS values.

In the graph, the raw signal of the longitudinal level is shown in black. The red signals describe the sliding standard deviation of the longitudinal level, with a window width of 3, 25 and 50 m. The blue signals result from the sliding RMS value with the respective influence lengths. The RMS values result from the following relationship:

$RMS_{sliding} = \frac{1}{n}\sum_i^{i+n}\sqrt{LL_i^2}$ with $n = 3$, 25 or 50 m and LL…Longitudinal level

In the lowest section of the figure, the two parameters are compared for an influence length of 50 m. It can be seen that the result is practically identical, which is to be expected since both parameters represent the "irregularity" of the longitudinal level. Even with an influence length of 25 m, the two parameters lead to the same result, but with somewhat greater inaccuracies. This results from the fact that the D1 signal, due to the inevitable inaccuracies of the filtering carried out on the measuring car, also contains certain wavelength components in the range above 25 m (and below 3 m). If the influence length is reduced further, implausible absolute values result for the standard deviation of longitudinal level. These are clearly lower than those with an influence length of 25 or 50 m, which does not correspond to expectations. The standard deviation of longitudinal level with an influence length of less than 25 m is therefore demonstrably not applicable as a performance indicator, since the window width of the standard deviation must correspond at least to the largest wavelength contained in the signal.

The calculations of the RMS value show plausible results for all influence lengths. For the purpose of a detailed evaluation, the influence length of 3 m is followed. The RMS values at 3 m influence length practically correspond to the absolute values of the raw signal without including negative amplitudes. Considering that the smallest wavelength of the raw signal is 3 m, this result can be explained mathematically. According to the described contexts, the sliding RMS values of longitudinal level with an influence length of 3 m are used for further calculations.

Since there are no negative values, RMS values can be processed differently than the raw signal. In the next step, the RMS values from the beginning to the end of the turnout are cumulated and scaled by the length of the turnout. Fig. 5 shows the resulting curves for several measurement runs of a turnout.

The dotted line describes the cumulative RMS values of a measurement run in 2016, the last run before tamping is carried out. The black continuous curve describes the first measurement run after tamping. It can be clearly seen that the curve is pushed downwards by the maintenance task. The course of the further measurement runs is shown by means of a colour gradient (black - green -orange - red). It is clearly visible that the curves reach higher values over time indicating track geometry deterioration. Particularly problematic areas can also be identified by exploring the gradient of the curve. With large gradients, the RMS values are high and the cumulative curve rises sharply. In the case shown, this is the case between −120 data break to −60 data break (one data break is 25 cm, 0 is the crossing nose).

Although a lot can be gained from this representation after appropriate considerations, a straightforward representation of time series is only possible with difficulty. In addition, a performance indicator for the entire turnout is needed for an automated evaluation. However, the advantage of the cumulative representation is that a meaningful quality index can be easily derived. The value at the end of the turnout (black dots in Fig. 5) represents the cumulative Track Condition Index (cTGI) of the turnout. Fig. 6 shows the cTGI over time.

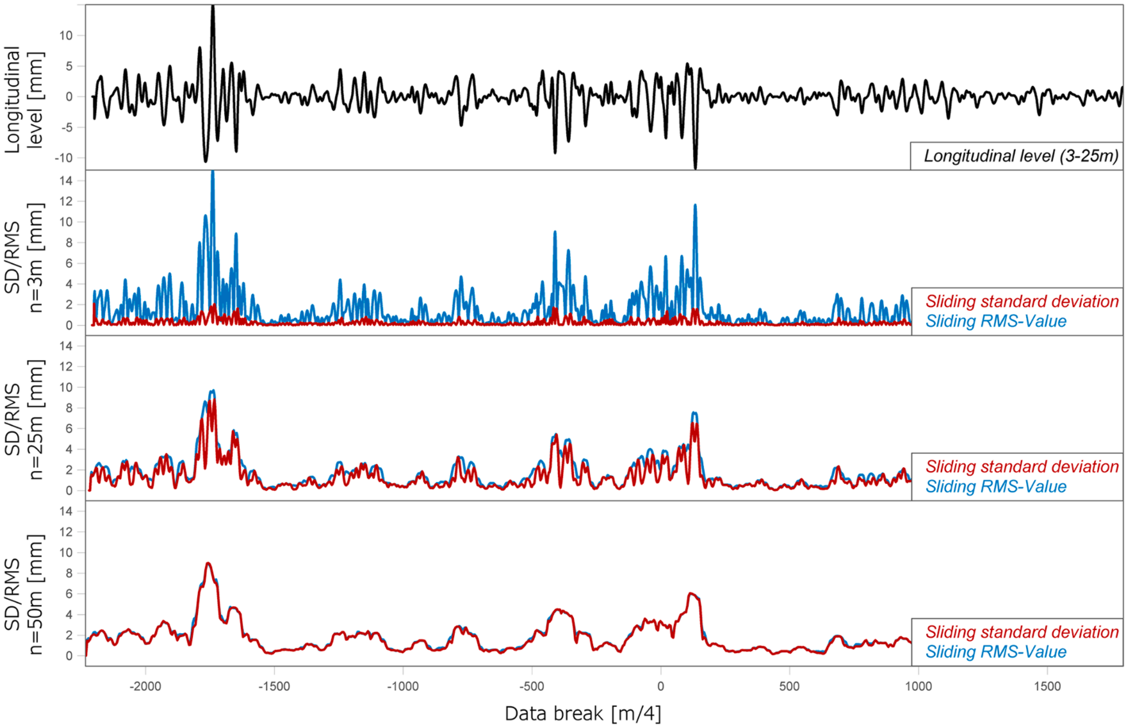


Fig. 4. Comparison of calculation methods.

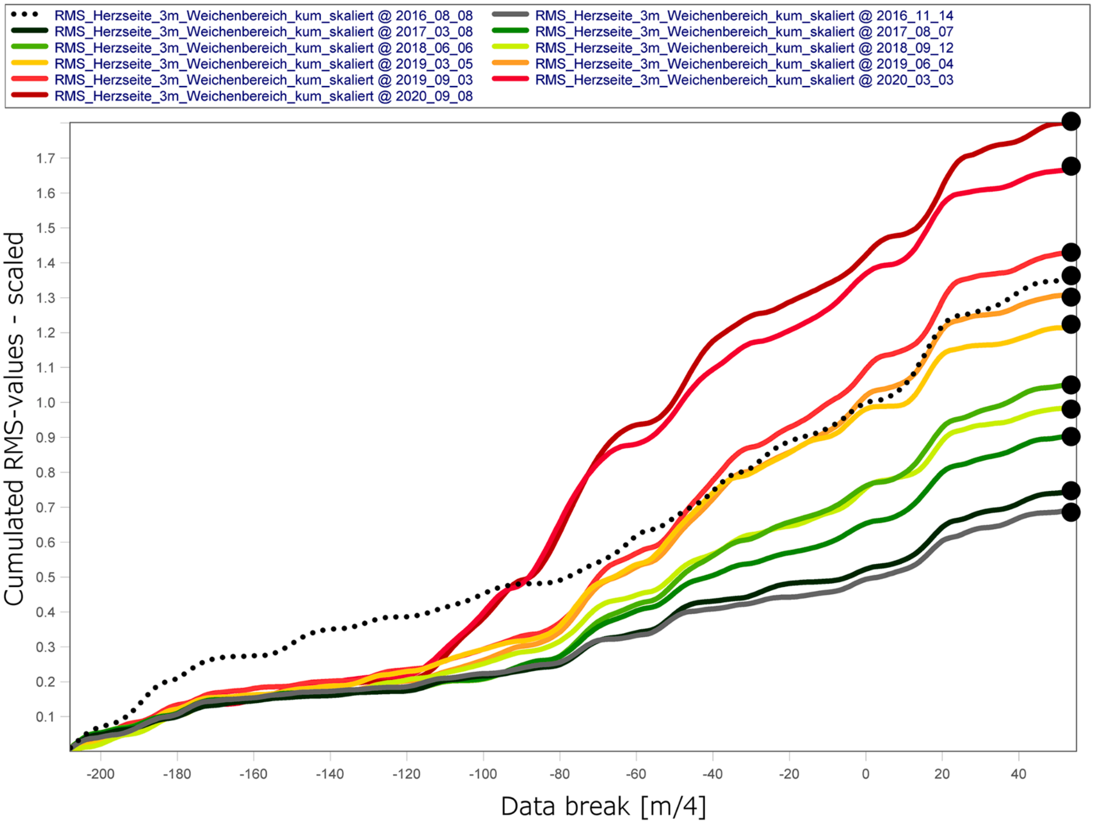


Fig. 5. Cumulative RMS values.

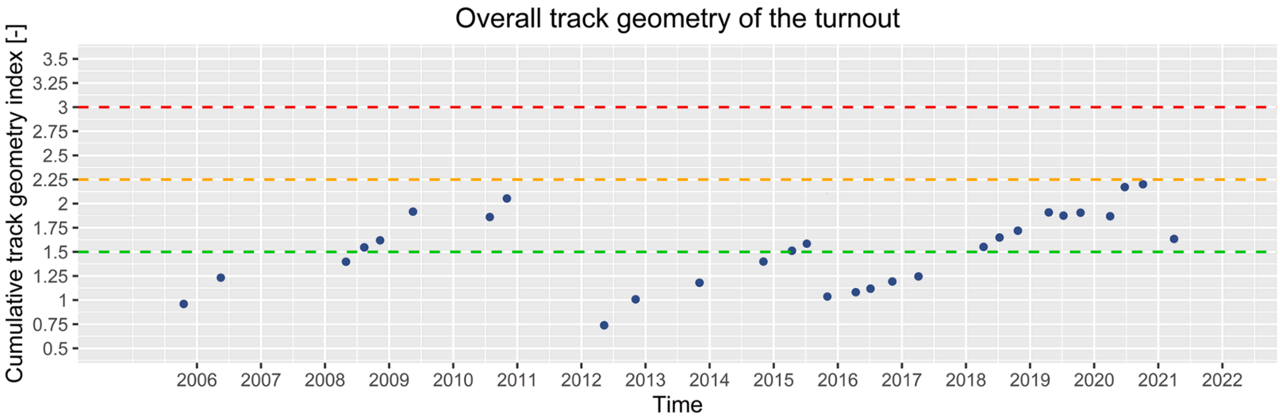


Fig. 6. Time Series of cumulative Track Geometry Index.

The time series is stable. Performed maintenance actions noticed already within the utilisation values are also clearly visible in the cumulative Track Geometry Index. After a significant enhancement of quality in 2012 (tamping), the quality index worsens (increasing values) over time until the end of 2015 (tamping) with a sudden improvement. The same characteristic can be shown from 2015 to 2021 when the next tamping task took place. The local maintenance measure in 2017, clearly visible within utilisation rates, has hardly any impact on the cTGI. As this is a new index, limits do not exist yet. The horizontal lines drawn in Fig. 6 only reflect the indications of good and poor quality based on the evaluation of 40 turnouts. After installation, the index is below the green line for most turnouts, shortly before the renewal it is in the upper range.

It has to be checked whether turnouts with a relatively large longitudinal extension possibly show comparatively good cTGIs using this methodology, since the homogeneous partial sections of these turnouts are proportionally longer than those of turnouts with a small longitudinal extension. It should be countered that this fact corresponds to reality and particularly critical areas are mapped by means of utilisation rates anyway. Should this correlation prove to be problematic, however, it is easily possible to compensate for it by means of switch length-dependent calibration factors.

2.4. Segmentation of turnout sections

With help of the above described indices, it is possible to assess the condition of track geometry for a turnout over time. In a further step, prognosis (linear model) are enabled. However, for an even better understanding of problematic zones of a turnout, we recommend further segmentation into subsections. This allows for distinguishing between good and poor sections of the turnout. Of course, the (absolute) data positioning quality must allow this segmentation. However, with the mentioned methodology problems have not occurred so far. A meaningful segmentation includes the maintenance protocol of the infrastructure manager. In Austria, the infrastructure manager has taken over the segmentation given by the turnout installation. For the majority of the turnouts, three panels are manufactured within the construction hall, are transported to the construction site in one piece and connected with welds on site. The three panels are the "Switch panel" including the switching device, the "Closure panel" and the Crossing panel with the crossing. Fig. 7 gives an overview on these sections.

Additionally to these three panels, we include a "Front" and a "Rear" section into the evaluation, both with a length of 10 m. These sections are technically not part of the turnout, but include in many cases insulated rail joints. Insulated rail joints often lead to poor track quality due to the dynamic excitation. If the quality of track is poor around the turnout, this also impacts the quality behaviour of the turnout itself. Therefore, we recommend to include these sections for the condition assessment of turnouts.

The quality indices described above are calculated for the five turnout sections. For utilisation rates, the highest amplitude of every single section is brought into relation to the respective limit. As for a clear visualisation of every section the number of indices have to be reduced, we only take the alert limit (AL) into account. However, every limit can be chosen. The cumulative Track Geometry Index is scaled by the included section length so that a calculation for the five subsection is possible without further adaptations. Again, using the common approach of calculating the standard deviation would not lead to correct results as the minimal impact length for the D1 range of longitudinal level is 25 m. The shortest regular constructed turnout in Austria has a length of 27 m. Here, a visualisation of the subsections would not be possible with the standard deviation method while for the described method with an impact length of 3 m no issues occur.

3. Results

Putting everything together, we achieve the assessment shown in Fig. 8. On the left side, the time stamps of the measurement runs are printed. The five subsections are shown at the top of the figure. For each subsection and each measurement run, two quality indices are printed. The left one contains the index value for the cumulative track geometry, the right one the degree of utilisation. For both indices, we used a colour code with 4 categories. These categories correspond to the horizontal lines in Fig. 6 and are to be understood as a preliminary draft. We integrate the historical maintenance tasks (in relation to the track geometry), visible as horizontal, dotted lines. The direction of travel can be relevant for a better understanding of the quality behaviour (if the quality of one section leads to higher dynamic loads in the next section) and is therefore indicated at the bottom of the figure.

In the example presented, a clear difference in quality can be observed between the turnout sections. The most serious differences are identified between the closure panel and the crossing panel. The closure panel shows very low values from 2010 to 2021. Looking at the deterioration branch between 2015 and 2020, a gradual deterioration can be observed (from 0.4 to 1.1), with 1.1 still reflects a very good condition of the track geometry. This is the reason why the maintenance measure at the end of 2020 had no significant impact on this section. The crossing section, on the other hand, starts with an index value of 1.5 (at 2015.8) and experiences a rapid deterioration to 3.9 (at 2020.8) - this reflects poor quality. The maintenance carried out comes along with a clear improvement in quality (index value 2.2). Note that the index value in the intersection area (2019.3) is an outlier, no measures were carried out here. The three other sub-areas also show a corresponding deterioration over time, the condition is in the medium-good range.

4. Discussion and outlook

The developed data sheets can be considered as a tool for a more efficient and objective assessment of turnout condition. By applying the method to all turnouts of the main network (for branch lines the measurement interval is too long to have sufficient data), the x% of the turnouts with the worst condition can be filtered out by the infrastructure manager. This can also be done for partial sections of turnouts, which opens the way for correlation analyses, e.g., for the frog area. Certainly, further considerations are necessary when transferring the methodology to the entire network. The method described is only applicable to turnouts that are regularly measured with the track measurement car. This applies to all turnouts of the main track, but not to the entire network. The index calculation and data sheet visualisation is largely automated and therefore does not represent a restriction. However, the positioning remains a challenge for a network-wide scaling of the method. Although this process is also largely automated, it still has to be verified by the user. This is currently being discussed with the infrastructure manager.

Based on the investigations for open track, the next step is to perform economic evaluations for turnouts with regard to a quality threshold for the cumulative track geometry index. These evaluations should include network data and a corresponding clustering of the boundary conditions. Once appropriate quality levels for the index have been established, these can be implemented in a predictive tamping regime for turnouts. Of course, similar assessments need to be carried out for other measures, especially for the economically dominant measures of sleeper replacement, frog exchange, switch rails replacement, and ballast cleaning/replacement. For the latter, Fellinger has already proposed an index as part of his PhD thesis [25]. The others are part of our on-going research. When solutions for these questions are available, life cycle assessments will be possible.

5. Summary

Turnouts are costly and safety critical assets. This asks for a standardized and automatized assessment similar to the one already implemented for open track based on loaded measurements achieved from track recording cars. The data gathered from these vehicles cannot be used directly for turnouts. Infrastructure managers assess switches and crossings differently by applying frequent inspections. While safety is guaranteed following this process, objective judgment on the turnout condition cannot be supported using unloaded measurements. As shown in this paper, we aim for different pre-processes in order to make standard track recording car's data available for a standardised turnout assessment. We have investigated two indices for assessing track geometry within the turnout, the cumulative track geometry index and utilisation rates. These indices prove to deliver stable and useful information for both the entire turnout and turnout sub-sections. In the

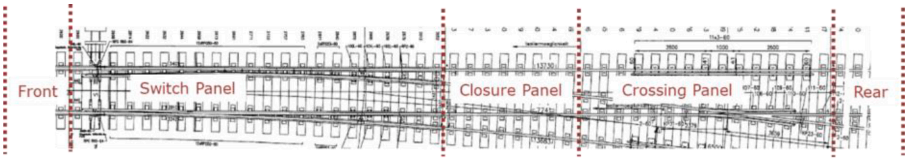
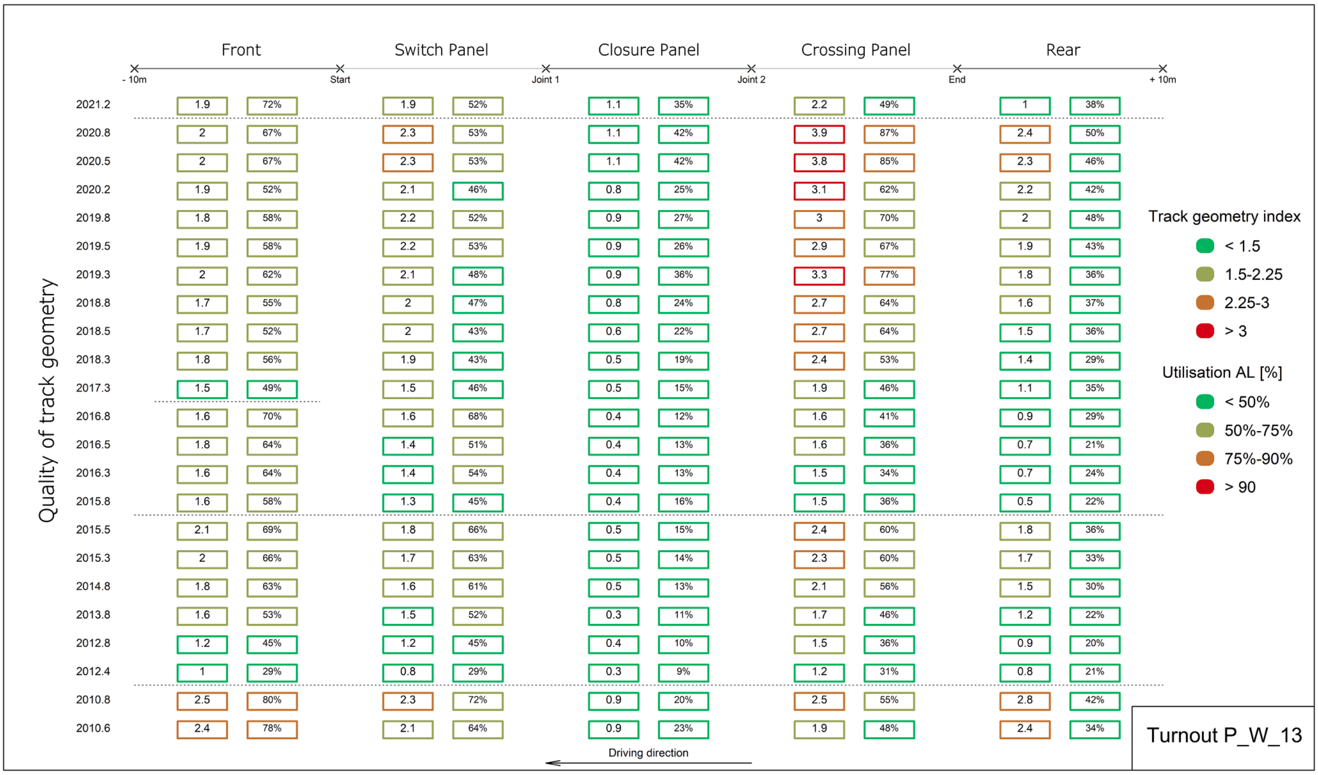


Fig. 7. Turnout segmentation.



	Front		Switch Panel		Closure Panel		Crossing Panel		Rear	
2021.2	1.9	72%	1.9	52%	1.1	35%	2.2	49%	1	38%
2020.8	2	67%	2.3	53%	1.1	42%	3.9	87%	2.4	50%
2020.5	2	67%	2.3	53%	1.1	42%	3.8	85%	2.3	46%
2020.2	1.9	52%	2.1	46%	0.8	25%	3.1	62%	2.2	42%
2019.8	1.8	58%	2.2	52%	0.9	27%	3	70%	2	48%
2019.5	1.9	58%	2.2	53%	0.9	26%	2.9	67%	1.9	43%
2019.3	2	62%	2.1	48%	0.9	36%	3.3	77%	1.8	36%
2018.8	1.7	55%	2	47%	0.8	24%	2.7	64%	1.6	37%
2018.5	1.7	52%	2	43%	0.6	22%	2.7	64%	1.5	36%
2018.3	1.8	56%	1.9	43%	0.5	19%	2.4	53%	1.4	29%
2017.3	1.5	49%	1.5	46%	0.5	15%	1.9	46%	1.1	35%
2016.8	1.6	70%	1.6	68%	0.4	12%	1.6	41%	0.9	29%
2016.5	1.8	64%	1.4	51%	0.4	13%	1.6	36%	0.7	21%
2016.3	1.6	64%	1.4	54%	0.4	13%	1.5	34%	0.7	24%
2015.8	1.6	58%	1.3	45%	0.4	16%	1.5	36%	0.5	22%
2015.5	2.1	69%	1.8	66%	0.5	15%	2.4	60%	1.8	36%
2015.3	2	66%	1.7	63%	0.5	14%	2.3	60%	1.7	33%
2014.8	1.8	63%	1.6	61%	0.5	13%	2.1	56%	1.5	30%
2013.8	1.6	53%	1.5	52%	0.3	11%	1.7	46%	1.2	22%
2012.8	1.2	45%	1.2	45%	0.4	10%	1.5	36%	0.9	20%
2012.4	1	29%	0.8	29%	0.3	9%	1.2	31%	0.8	21%
2010.8	2.5	80%	2.3	72%	0.9	20%	2.5	55%	2.8	42%
2010.6	2.4	78%	2.1	64%	0.9	23%	1.9	48%	2.4	34%

Fig. 8. Visualisation of the developed indices for subsections of turnouts.

challenging future of railway infrastructure with increasing traffic and decreasing available staff, such a data-based assessment will be necessary.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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