Innovative track geometry data analysis for turnouts

Preparations to enable the turnout behaviour description

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Abstract

Turnouts are expensive but essential railway infrastructure components. Approximately 13,600 turnouts are located on the Austrian Federal Railways network. The average age of these turnouts is over 22 years. A turnout is an assortment of many individual parts and in addition, has some moveable elements. These two facts lead to high wear and very close inspection intervals. Therefore, new approaches are necessary to rate the actual condition very precisely and to forecast the remaining service life. In contrast to the open track, the inspection of turnouts is still carried out manually and based on this data it is not possible to describe or predict turnouts behaviour over time. In order to change this situation, the identification of the life-limiting components of turnouts will first be necessary. Having this knowledge, there is still a need to search for other sources of data to describe the condition and to predict the behaviour. The prerequisite is that this data is measured under load, so that the real behaviour of a turnout can be assessed during the passage of a rail vehicle. The measurement data from the track-recording car EM 250 seems to be best suited for that challenge. Nevertheless, a very extensive positioning process for these measurement data will be necessary to derive a dataset fulfilling all the requirements. This algorithm enables on the one hand the synchronization of all measuring signals and on the other hand the identification of the individual areas within the measurement signals. Consequently, after applying this positioning algorithm to the measurement data, it will be possible to describe the life-time limiting components' condition. In order to handle the great amount of different data, a platform with the name *CoMPAcT* was introduced. Within this environment, it will be possible to store all the information relating to the respective turnout, while also to carry out analyses either for specific turnouts or for all existing ones. In addition to measurement data, all other information (performed maintenance activities, inspection results, geometric designs, etc.) is specifically implemented for each considered turnout.

Keywords: Turnout, Measurement data, Data positioning, Measurement car, *CoMPAcT*

1. Introduction

Turnouts are important parts of the railway infrastructure. Their purpose is to allow a rail vehicle to move from one track to another without interruption. On the core Austrian Federal Railways network, comprising 9,724 track kilometres in total, 13,592 turnouts are situated [1]. This corresponds to an overall density of 1.4 turnouts per track-kilometre. The infrastructure manager must give priority to these assets due both to this high value as well as to the high frequency of necessary inspection tasks.

In Austria, the average age of turnouts, calculated over all track categories and turnout types, is about 22 years. Based on an average technical service life of 33 years [2], both the description of the turnout behaviour and the prediction of maintenance tasks are major challenges. In order to transfer the high investment costs into a long service life, continuous monitoring, status recording and executing maintenance activities at the right time are prerequisites. According to the re-investment process for turnouts, the primary necessity is being able to describe the current condition and to predict the development over the next few years. Furthermore, it is essential to know about the critical components leading to a reinvestment, in the event of excessive wear and tear or poor and incorrect performance.

2. Specification of lifetime limiting components

Since turnouts consist of many individual parts and have a varying stiffness over their length, an identification of the critical and therefore lifetime limiting components is required in the run-up to a condition description model. To do this, two different approaches have been used within an end-of-life dissection.

2.1 Renewal project analysis

The Austrian Federal Railways list of renewal projects from the year 2015 is the basis for the first analysis. It was possible to extract the actual condition from this survey (based on manual inspection data) together with the reasons for the replacement of those turnouts, which are putatively at the end of their service life. Of course, the entries in such project lists range from very general to extremely detailed descriptions. Nevertheless, in most cases it is not only one reason that is given. The results of these examinations are subdivided according to the material of the sleepers, their different operational behaviour and their area of operation. The evaluation focuses on 609 turnouts with wooden sleepers and on 20 turnouts with concrete sleepers. The results of this analysis are shown in figure 1.

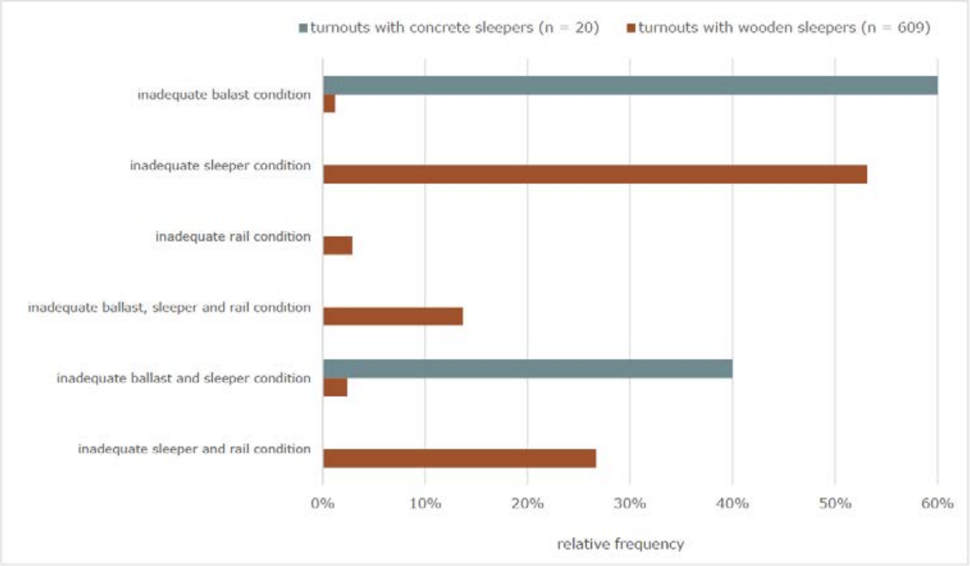

Fig. 1: Turnout reinvestment causes in 2015.

One hundred percent of the turnouts with concrete sleepers that were examined were replaced due to an inadequate ballast condition. Additionally, in forty percent of the examined cases, a poor ballast condition accompanied by a bad sleeper state led to a renewal. The situation varied more in the case of turnouts with wooden sleepers. Fifty-three percent of the turnouts with this sleeper material were replaced only due to an inadequate sleeper condition. In twenty-seven percent of all observations, a renewal was necessary due to high rail wear combined with an inadequate sleeper condition. Additionally, the condition of the ballast in combination with other components led in seventeen percent of all cases to an exchange of the turnout, especially on tracks dealing with heavy traffic loads.

In summary, the ballast seems to be very critical at turnouts with concrete sleepers. In the case of turnouts with wooden sleepers, on the one hand, the sleepers themselves and on the other hand, these components coupled with an inadequate ballast and rail condition were shown in most cases to be responsible for the end of the technical service life. The considered turnouts were installed on different lines as well as under different subsoil ratios and thus under different boundary conditions. It is thus not possible to make general statements on the issue and further investigations are necessary to identify the critical components and to verify the presented results.

2.1 Standard element analysis

Turnouts consist of various components such as the switch toes and the switching machine, the crossing nose, the closure rails and the wing rails. Furthermore, turnouts have different basic conditions such as their turnout type, their daily traffic load, their operating area or their sleeper material. Exactly one specific combination of these parameters defines a standard element, which therefore maps the standardized (average) behaviour of similar turnout elements used in a railway network [3]. Furthermore, the necessary maintenance activities were determined during the entire life cycle for each standard element. These are termed standard work cycles and they are available for each frequently occurring parameter combination in Austria. These work cycles are based on statistical analyses of historic maintenance measures, service lives and renewal demands. Therefore, they correspond to the actual mean service intervals within the network. The standard elements thus describe a typical situation in the railway network under consideration. Accordingly, this assumption is valid and delivers correct maintenance and renewal demands [4].

In consequence, this methodology describes a network-wide mean, which is the reason why it is not directly transferable to a specific turnout within the railway network. By multiplying the number of the maintenance tasks within the work cycle with their specific charges, it is possible to calculate the life cycle costs (LCC) of the turnout types considered. As mentioned above, the standard element methodology describes a network-wide mean value for a given parameter set. The calculated life cycle costs are thus an average value for all turnouts with the boundary conditions or parameters. The calculated life cycle costs comprise both the operation and maintenance costs together with the costs for replacement and disposal but do not include the costs of development, testing and homologation.

By discounting and summing up all the single payments to a reference year (in this case the year of reinvestment) it is possible to calculate the net present value (NPV), assuming the determination of a discounting rate (e. g. 5%). The average dynamic annual cost is calculated by multiplying the NPV using the capitalizing factor (CF). If these steps are carried out separately for each year of service life, the so-called annuity monitoring [6] is obtained and by finding the minimum within this cost function it is possible to predict the best time for re-investment. Furthermore, it is also possible to compare two different technical options and by this means to identify the critical components, which in the case of a failure would lead to a re-investment.

After extending the service life and calculating the annual costs for both turnout types, it is possible to identify the critical and life-limiting components by using the dynamic annual costs monitoring method (figure 2). The methodology of annuity monitoring was subsequently used to identify the critical and thus life-limiting components of turnouts with concrete and wooden sleepers on an economic and network-wide base. For those with concrete sleepers, the standard work cycle was extended beyond 36 years. To justify the extension, the knowledge about reinvestment reasons from the projects list was used and ballast cleaning was thus planned as an additional maintenance task in year 36. Statistical analyses as well as historical data showed that the ballast has a useful service life of approximately 14 years following cleaning work under these boundary conditions. As a result, the overall service life could be extended to 50 years. For turnouts with wooden sleepers, the standard work cycle was simply doubled. To compensate the expansion of the life cycle, a full sleeper exchange was planned. Within the standard work cycle, the wooden sleepers have a useful service life of approximately 28 years under the conditions described. As a result, the overall service life could be extended to 56 years. All other maintenance tasks for both turnout types were not changed

The diagram at the top (figure 2) shows the annual costs function for a turnout with concrete sleepers. In the 34th year, the costs for ballast cleaning increase the annual costs to a higher level. Over the next 14 years, it is not possible to reduce the annual costs to a level that is lower than in year 34.

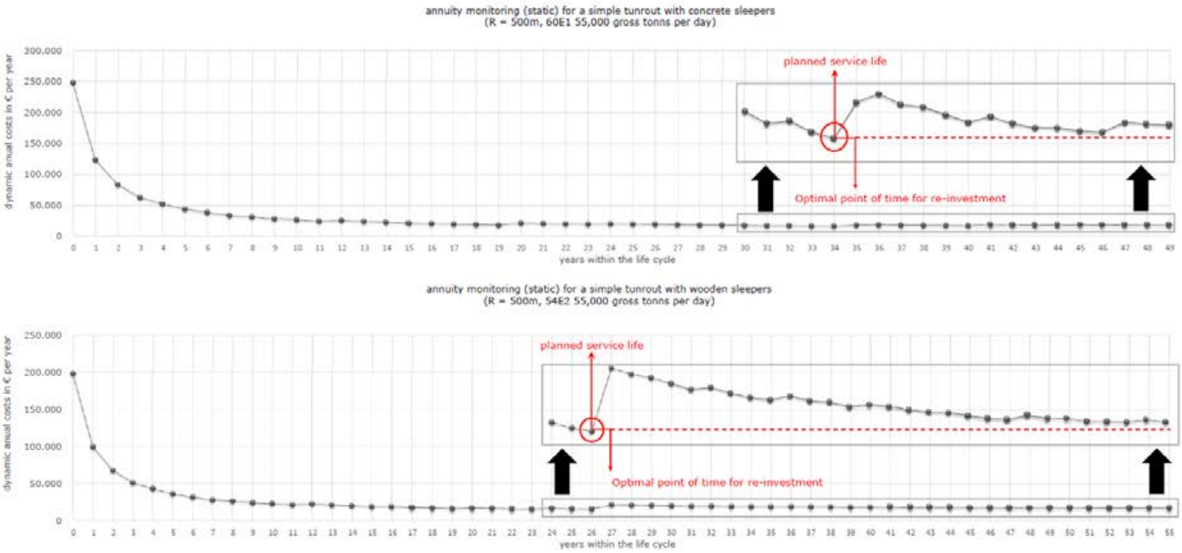

Fig. 2: Annuity monitoring (top: concrete sleepers, bottom: wooden sleepers).

The service life cannot be further extended, because in such a case an additional ballast cleaning task would be necessary. For this reason, it was possible to confirm the result on an economic basis that the ballast represents the critical component in turnouts with concrete sleepers. The second diagram (figure 2 - bottom) shows the annual costs for a turnout with wooden sleepers. The costs of sleeper replacement increase the annual costs drastically in the 27th year. Over the next 26 years, it is not possible to reduce the annual costs to a level lower than those of the previous period. In the case of a bad sleeper condition at the end of the service life, the average dynamic annual costs are always higher than in the case of a general renewal. The sleepers thus represent the critical component in turnouts with wooden sleepers, also from an economic perspective. Thus, the critical components are defined by project lists on the one hand, and on a very strategic level on the other hand. The attempt will now be made to describe the fundamental condition of these critical components.

3. Data preparation for a turnout description

Measurement signals are defined for describing the condition and the operational behaviour of these elements, based on knowledge of the critical components. In Austria, the core railway network is measured three or four times a year by the track measurement car EM 250. This measurement data, which is restricted to the through direction of the turnout and has mostly been available since 2001, should also be suitable for extracting helpful information for turnouts.

One challenge, according to this data source is the fact, that the track measurement car was designed to measure open track. Thus, the data supplied cannot be readily used to describe turnouts. In order to be able to implement raw-data-based analysis for turnouts, it is therefore necessary to position the measurement signals with a maximum deviation of one measurement point and to identify the individual components of the turnouts within the measurement signals. The behaviour of a turnout over time could only be analysed by examining the time series of the measurement data. A single measurement is able to show a limit violation but cannot be used to deduce the operational behaviour over a period of years.

Hence, the measurement data must be very precisely positioned in order to compare identical areas or cross-sections. For this reason, the next step is to generate a methodology for automated re-positioning of the measurement data with the necessary precision – for the entire time sequence of 17 years.

3.1 Post positioning process for measurement data

Research focused in a first step on a reference measurement signal, which offers following properties:

a. The reference measurement signal must have an unmistakable characteristic.
b. For a detailed positioning, a unique point of each single measurement record must be identified.
c. At least the necessary dependencies between the different measurement signals must be known.

Evaluations have shown that most of the listed properties are met by only one signal within the common main measurements. The half gauge signal of the rail in which the crossing nose is located, is used as a reference measurement (figure 3 – green signal). The half gauge is recorded via an optical system [5]. In the course of this measurement, the head of the rail is scanned 14 mm below the top side. The signal starts to skip to a higher level at the bend of the wing rails, which represents the first identification point. The signal rises until the measurement equipment can find the crossing nose. At this moment the crossing nose is high enough to be recognized and the signal thus jumps down to a lower level. The crossing nose has thus been detected and the second point for identifying the crossing panel has been found (theoretical crossing point tCP in figure 3). Furthermore, it is possible to automatically localize the first measuring point after the crossing nose gap (red circle within figure 3).

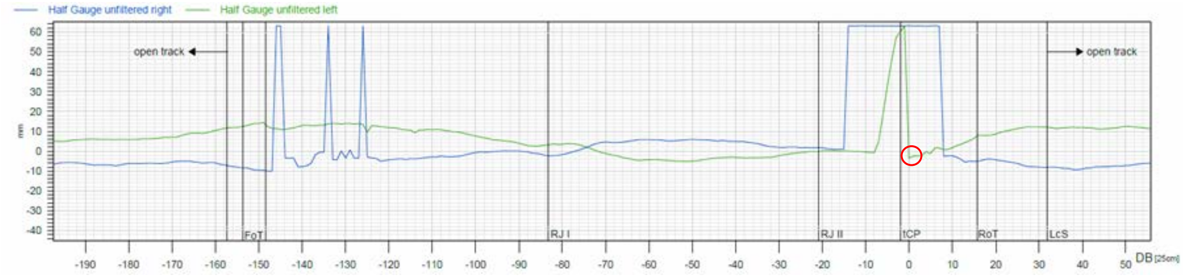

Fig. 3: The precisely positioned half gauge reference measurement signal.

It is thus possible to implement the necessary post positioning process with the required precision and also the area identification (FoT: front of turnout, RJ: rail joint, tCP: theoretical crossing point, LcS: last continuous sleeper). Based on this reference signal the synchronicity between the various measurement signals derived from known dependencies was subsequently analysed. If synchronicity was not given, it was established by differentiated stationing. In the context of the rail including the crossing nose, the synchronicity between the reference measurement and the full gauge signal could be shown by calculating a Euclidean distance function and evaluating the position of the minimum within this function. Thus a unique area identification is also possible in the full gauge measurement. These signals are used as standard analysing methods by evaluating the open track. These signals are now also available in the required precision level for evaluations of turnouts.

Unfortunately, due to the measurement principle [5], the full gauge signal is not present over the entire length of the turnout. Especially within the switch rail and the crossing nose area, the full gauge signal is not measured correctly, or respectively identified as an error value and corrected. Since this signal should be used to describe the condition of a turnout, other ideas are needed to map the areas where no gauge measurement is present. For this purpose, an attempt was made to prepare the rail cant and the rail base measurement in the same way as a means of obtaining the missing information. Again, this was possible since these two signals are measured by another system than the full gauge and both systems provide unique full gauge measurements. Thus, the synchronicity between the full gauge measurement and the rail cant, respectively the rail base measurement could be assessed.

In addition, the synchronicity between the full gauge measurement and the alignment signal was proved, since both are provided by two different measuring systems. An inertial measuring unit (IMU) is responsible for recording the alignment and therefore another dependency must be used: To calculate the alignment signal, the rotation measured by the IMU, is added to the measurement of the half gauge.

Thus, it is possible to check the synchronicity between these two measuring signals by filtering the half gauge signal to a wavelength range of 3 to 25 m (using a 4th order Butterworth band pass filter) and subsequently by comparing it with the alignment measurement in the same wavelength range. These examinations have shown a slight deviation between the two systems, which could be eliminated by a differentiated post positioning. By means of this method, it was possible to honour synchronicity between the half gauge and the alignment measurement and to position the alignment signals with respect to the half and the full gauge measurement signals. Finally, the process could be carried out for all other measuring signals of the IMU. The entire post-positioning process is implemented within an algorithm, which automatically performs the positioning of the measurement data and also the initial data validation. The measurement data are fitted to the different turnout areas, stationed with a maximum deviation of 25 cm and therefore ready for analysing the turnout behaviour.

4. *CoMPAcT*

In order to handle this multiplicity of different measurement data, a database has been developed specifically targeting the assessment of measurement data for turnouts. *CoMPAcT* is an acronym for "Condition Monitoring and Prediction Analytics for Turnouts". This tool is comprised of three parts:

a. The post-positioned measurement data provides the basis for the turnouts under consideration. These data are stored within a special framework to enable further structured analyses.
b. A visualisation within different measurement pages is possible to provides an opportunity to familiarize turnout experts with the measurement signals and learn the significance of them.
c. The implemented data framework allows analyses either for each single turnout individually or for all the turnouts that are under consideration.

CoMPAcT collects all the necessary data in a structure allowing a quick overview of the current condition as well as deep analysis about different turnouts.

5. Conclusion

Turnouts are important and very complex railway infrastructure assets, which are essential for safe and efficient railway operation. The presented study focuses primarily on simple turnouts, as these represent the most common types in the Austrian Federal Railways network. In order to be able to describe the actual condition of a turnout, it is necessary to determine the critical and thus life-limiting components. On the one hand, the reasons for a turnout renewal were extracted from project lists. On the other hand, the critical components were determined using standard elements and the annuity monitoring method. The ballast was identified as the life-limiting component for turnouts with concrete sleepers. The sleepers themselves were identified as the lifetime limiting elements for turnouts on wooden sleepers. Subsequently, measurement signals were defined for describing the turnout behaviour. These are values, measured under traffic loads, by the Austrian Federal Railways track measurement car EM 250. Unfortunately, the EM 250 car was developed for measuring the open track and not necessarily for the measurement of turnouts and hence a very extensive post-positioning process was necessary to obtain the required accuracy and synchronicity between the single measurement signals. All the information derived for turnouts is stored in *CoMPAcT*. It therefore represents a research database for the description of the turnout behaviour and also for the derivation of a prognosis over the lifetime.

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