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Smart Data for a Pro-active Railway Asset Management

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Abstract

Rail infrastructure managers must work with increasing sustainably and efficiency as they are faced with increasing cost pressure. Against this background track engineers face a growing difficulty in legitimizing essential measures owing to strict budget restrictions. This situation requires an objective tool enabling a proper condition monitoring as well as component-specific, preventive maintenance planning.
The present research deals with such an evaluation of railway track condition using innovative track data analyses. Applying functional knowledge - both IT and railway skills – allows for extracting smart data out of big data for railway asset management. Due to a bottom-up approach this methodology enables both the establishing of net-wide maintenance and renewal demands and an in-depth assessment of specific track sections. The planning of specific renewal and maintenance measures for track sections and also strategic asset management will thus both be possible on a net-wide scale.

Keywords: Railway Infrastructure; Asset Management; Track Data Analyses, Fractal Analyses; Maintenance Planning, Renewal Planning, Infrastructure Budget

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1. Introduction

The operation of railway infrastructure requires major capital investment. ÖBB Infrastructure AG, for instance, invested 611.4 million euros in renewal and expansion and 493.3 million euros in maintenance of their assets in 2014 alone (ÖBB Infrastruktur AG 2015). An essential part of the duties of a railway infrastructure manager is establishing a balanced maintenance and reinvestment strategy, as also the related efficient use of tied capital. This is to mitigate potential safety risks and also to ensure compliance with availability targets and handle the ever-increasing cost pressures. This area of responsibility is summarised by the term asset management. According to the Rail System and Communications Department (2011) Modern asset management must focus on three main issues:

- The balance between maintenance, renewal and enhancement,
- The link between infrastructure managers and contracting companies,
- The combination of the strategy and its implementation based on an evidence-based decision making.

In order to ensure that this is achieved, it is crucial to first record the asset condition and describe its development through time. There are many ways of recording the asset condition. The most objective and efficient way is to measure it directly using state-of-the-art track recording cars, since these allow infrastructure managers to record a large volume of measuring data covering the entire network several times a year. Specific analysis methods can help infrastructure managers classify and visualise the data collected. In order to use this data in a smart way a component-specific condition monitoring is required to take the right measure at the right time. Moreover, this forms the sound basis for a sustainable asset management.
In the track context, the major factors for life cycle costs are the components sleeper, ballast and substructure since these are mainly responsible for its service life. With the methodologies used for track analyses at the present time, a failure in track geometry can be detected, sometimes even predicted. However, the root cause of poor track quality often remains unknown. Fractal analyses of vertical track geometry allow identifying the root cause by also analysing the wavelengths of the track geometry signal and not only the amplitudes. There is no need for any other measurement except the already existing longitudinal level.

1.1. Life Cycle Costs of Railway Track

In order to ensure a proper asset management, the life cycle costs of the asset must be considered. For railway infrastructure the main matter of expense is track. The life cycle costs of railway track are mainly defined by depreciation, maintenance and costs of operational hindrances (Veit 2007). From an economic point of view, depreciation decreases with increasing service life. However, costs of maintenance and consequently costs of operational hindrances grow. As a result annuities reach their minimum before the influence of increasing maintenance costs grow too large. Therefore, the ideal point in time for track renewal (economic service life) is defined by the minimum of annuities (Fig. 1).

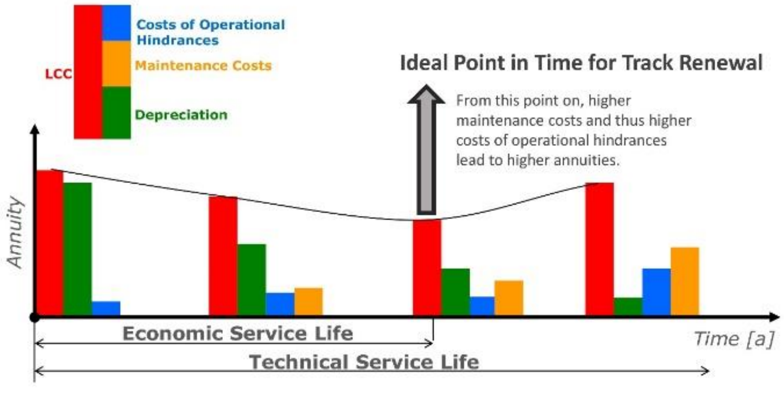

Fig. 1 Life cycle costs of railway track.

Both service life and maintenance demands – leading to costs of operational hindrances – are solely dependent on the technical behaviour of track. Consequently, it is crucial to evaluate the condition of track in order to establish a sustainable and efficient asset management.

1.2. Need for Innovative Track Data Analyses

The main questions for an asset manager are: “What is the main cause for track renewal?” and “What is the residual service life of track?” Up to now, it was not easy to answer these questions since it requires an identification of those components limiting the service life and a separate evaluation of their conditions. Technically, the economic service life is mainly influenced by the condition of sleepers, ballast, and substructure, since rail exchange can be executed separately at a much lower cost level. For superstructure with wooden sleepers, their condition is the limiting factor. Superstructures equipped with concrete sleepers will reach the end of their service life due to ballast deterioration (Berghold 2016, Landgraf 2016a). For concrete sleepers equipped with under sleeper pads (USP), much longer service lives can be achieved, but ballast condition remains the limiting factor. In addition to these two components, the substructure condition is also a crucial factor. In some cases, life cycle costs of track can be up to seven times higher due to insufficient substructure conditions as service life can be as low as only half (Veit 2007). Therefore, sleepers, ballast and substructure are the three types of components dealt with in the present paper.

In order to establish net-wide strategies (Fig. 2) this condition evaluation needs to be carried out for the whole network. Moreover, it should be carried out on a regular basis to monitor the behaviour over time enabling prediction of future maintenance and renewal demands. These requirements can only be met by using track measurement data. State-of-the-art track recording cars allow the recording of large measuring data volumes covering the entire network several times a year. The difficulty, however, lies in interpreting and handling this huge volume of data. Several methods of analyses can help the infrastructure operator classify and visualise the data collected.

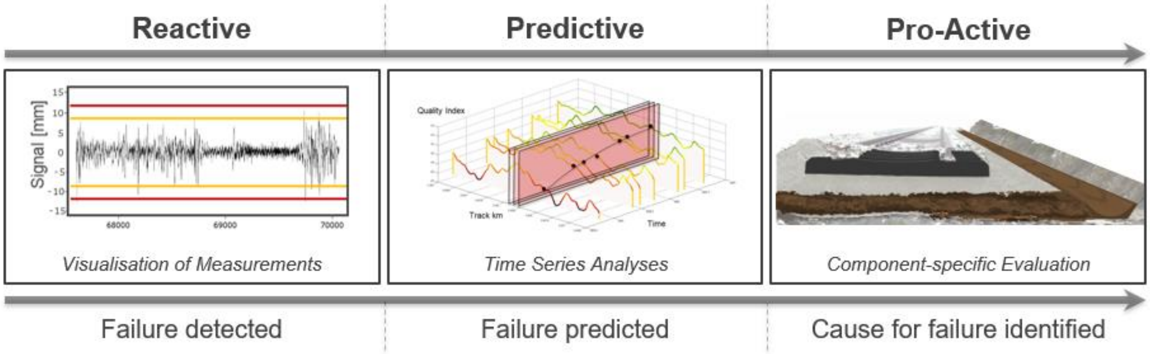

Fig. 2 Maintenance and renewal strategies for railway asset management.

For decades, different types of track signals have been measured by track recording cars. Without sophisticated data management, they can only be used to determine whether a value exceeds the intervention limit (EN 13848-5 2014). This *reactive* approach identifies the necessity of maintenance actions. In recent years, railway infrastructure managers have been collecting and storing the data in order to monitor the track’s behaviour over time. Consequently, this *preventive* approach allows for a prediction of when a maintenance action is presumably necessary.

The presented approach aims to go one step further by establishing a *pro-active* approach to answer the question which maintenance or renewal action has to be executed. This requires a component-specific condition evaluation. Such a methodology requires innovative track data analyses in order to distinguish the root cause for irregularities in track geometry. Only this approach allows evaluating the actual wear of the specific components enabling for determining the residual service life of track. This is a crucial input parameter for both economic and technical considerations as it enables determining depreciation within life cycle costs and planning the right measure to restore track quality.

2. Methodology for Track Condition Evaluation

In the track context, the components sleeper, ballast and substructure are major factors for life cycle costs as they are mainly responsible for its service life. Currently, the standard deviation of vertical alignment is used to describe track quality (Auer 2004), especially regarding ballast and substructure condition. While this type of analysis provides crucial information whether a tamping action is necessary, the condition of the specific components as well as their residual service life remains unknown. The methodologies established within this paper allow for identifying the root cause for failures and consequently the residual service life. This is also based on analysing the wavelengths within the specific signals and not only the amplitudes. There is no need for any additional measurement than the already recorded signals of longitudinal level and track gauge. The presented approach combines two methodologies of track data analyses for describing the different components: (1) Fractal analyses of vertical track geometry for quantifying the condition of substructure and ballast and (2) standard deviation of modified track gauge for evaluating the sleeper condition. These methodologies could be established and analysed within a data warehouse consisting of the main Austrian rail network. This data warehouse has been developed since 2006 at Graz University of Technology in close cooperation with the Austrian Federal Railway (ÖBB). It consists of both asset information as also measurement data recorded since 2002. The approach could thus be applied to 4,000 track kilometres with a time series of 14 years.

2.1. Fractal Analyses of Vertical Track Geometry

The methodology of fractal analysis is not new. Mandelbrot (1967) developed it in 1967 as an answer to an essentially fictional problem - not thinking of its possible benefits for the rail industry. His considerations centered on a historical question: the exact length of the coastline of Great Britain. As it was impossible to approximate the length of the karstic coastline of Great Britain with sufficient accuracy using Euclidean geometry, Mandelbrot tried to do so using a polygonal chain. This is how he developed the Modified Divider Method (Mandelbrot 1989). In 2002, Hyslip (2002) realised the potential this provided for analysing rail track geometry and tested the calculation method on a corridor section of AMTRAK. This approach was refined and implemented within the Institute’s data warehouse. Thus, it was possible to conduct analyses of this kind on a big scale for the first time (Landgraf et. al 2014, Landgraf 2015).

This analysis methodology is based on the fact that vertical track geometry can be derived from a sum of harmonic irregularities with different wavelengths and their amplitudes. Mean values or standard deviations, as commonly used, focus on the amplitude of defects within the alignment, but neglect the wavelength, i. e. the characteristic of a failure. Fractal analysis of vertical track geometry describes the characteristic of a failure by delivering expressive and informative quality figures in a comprehensible way. The Modified Divider Length Method (Mandelbrot 1989) enables us to split vertical deflections into their different ranges of wavelengths. We divide the wavelength ranges into short-waved (wavelengths: 1 m-3 m), mid-waved (3 m-25 m) and long-waved (25 m-70 m) errors (Fig. 3). Deflections in vertical track geometry, that are caused by ballast problems are more likely to occur within the mid-waved range while deflections caused by insufficient substructure conditions are expected to appear as wavelengths larger than 25 m. Short-waved errors implicate an inadequate interaction between sleepers and ballast also known as ‘hanging sleeper’. Mid-waved as well as the long-waved ranges are described in EN13848-5 (EN 13848-5 2014) as wavelength ranges D1 and D2.

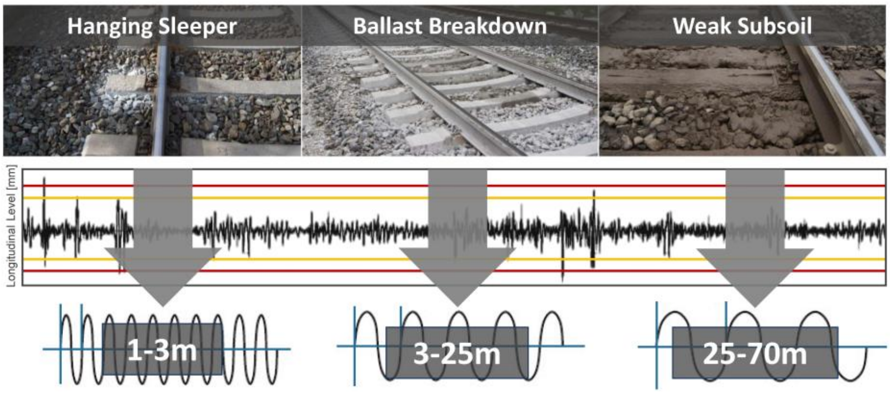

Fig. 3 Methodology of fractal analyses of vertical track geometry.

This methodology allows the distinguishing of whether irregularities within track geometry are caused by the interaction between sleepers and ballast (hanging sleeper), ballast breakdown and fouling respectively or weak subsoil condition.

2.2. Standard Deviation of Modified Track Gauge

The standard deviation of modified track gauge grasps the short-waved irregularities within the signal of track gauge, since longer wavelengths excessively influenced by gauge widening in curves. This short-waved noise describes the force interaction between fastenings and sleepers. In the case of concrete sleepers, a decreasing value of standard deviation of modified track gauge shows the necessity of a rail pad exchange. For wooden sleepers, a decreasing value indicates a degradation of the force transmission between screws and sleepers, limiting their service life.

Figure 4 shows the measurement signal of track gauge as also the modified signal and its standard deviation (Landgraf 2016b) for a track section of 100 m. Highlighted within the red area, the latest value of standard deviation from the modified signal differs essentially compared to the earlier condition. This massive improvement, illustrated by the standard deviation from the modified signal, can rarely be seen within the initial measurement values of track gauge. After analyzing the related track section in-situ, it could be verified that track maintenance was carried out in the form of a screw-hole renewal. Thus the force transmission between the wooden sleeper and the screws was improved in this area which counteracts the jittering within the signal. As a result, the value of standard deviation of modified track gauge decreases. This shows that standard deviation of modified track gauge provides a condition evaluation of the sleepers as also an evaluation of force transmission between sleepers and fastenings.

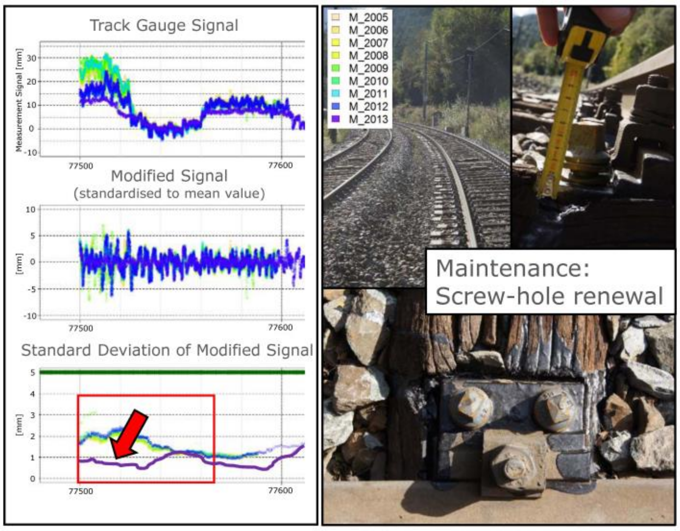

Fig. 4 Methodology standard deviation of modified track gauge.

2.3. Validation and Implementation

Fractal analyses of vertical track geometry as well as standard deviation of modified track gauge was applied on the main network of Austrian Federal Railways (ÖBB) including 4,000 km and times series since 2002. As a third main part of input data, evaluations from Ground Penetrating Radar (GPR) are included. This geophysical measurement allows for an examination of the ballast bed and the substructure. The Austrian Federal Railways have been evaluating 1,400 km using GPR. The applied system delivers information on Ballast Fouling, Ballast Humidity, Ballast Undulation, Interlayer Humidity, Interlayer Undulation, and Clay Fouling.

For all these evaluation methodologies, a profound validation process (Landgraf 2016a) has been executed combining two approaches: First, recorded maintenance actions and track renewals have been compared to the behaviour of fractal analysis over time, the standard deviation of modified track gauge and evaluations from GPR. Fractal analysis, for example, showed a significant improvement after ballast cleaning (mid-waved dimension) and substructure rehabilitation (long-waved dimension), respectively. Second, it was possible to validate these analyses to the in-situ behaviour of track. In doing so, track inspections have been carried out for visual evaluation. Moreover, soil mechanical approaches like cone penetration tests (CPT) or in-situ excavations have been executed during the validation process. Finally, a statistical correlation analysis - using Spearman’s rank correlation coefficient - between the different methodologies has been executed. As a result, it can be stated that these evaluation methodologies allow for a description of the component-specific condition of track.

Recently, fractal analyses and standard deviation of modified track gauge were implemented within swissTAMP which is the tool for track analyses and maintenance planning of Swiss Federal Railways (SBB). This allows for working with data containing another 4,000 km of track with time series since 2007. Thanks to the geotechnical department within SBB it was able to correlate fractal analyses to net-wide geotechnical surveys conducted within the last five years (Fig. 5).

The left illustration of Figure 5 shows the evaluations of 632 ballast samples which could be correlated to the mid-waved fractal value. Within these ballast samples the proportion of fines – i.e. degree of ballast fouling – was tested on every cross section. The correlation analysis shows that the higher the degree of ballast fouling, the higher the values for the mid-waved range of fractal analyses. Thus, fractal analyses enable evaluation of the ballast condition.

Similar analyses could be conducted for the long-waved fractal value (Fig. 5, right). This value – evaluating the substructure condition – was correlated with the load bearing capacity measured by dynamic plate tests.

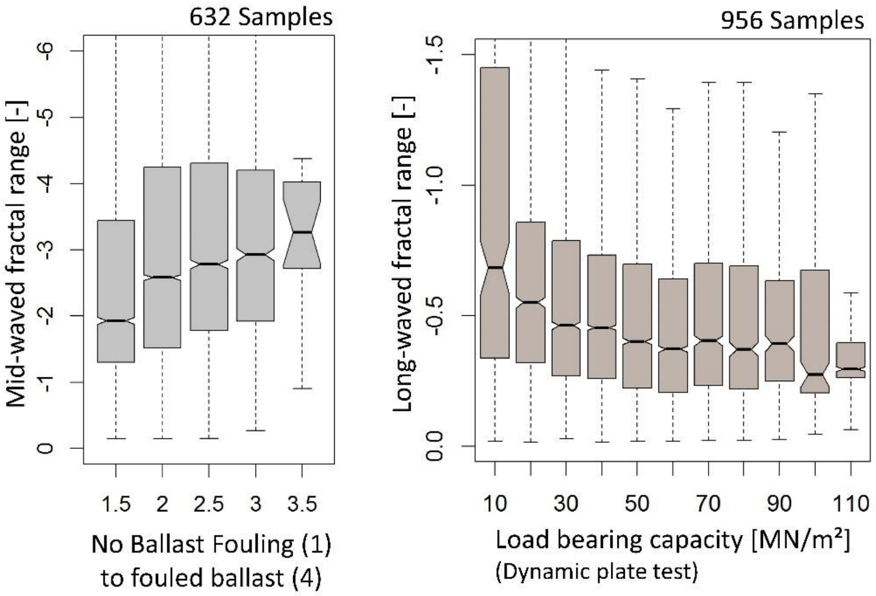

Fig. 5 Correlation analyses for fractal analyses of vertical track geometry.

These correlation analyses prove that the higher the load bearing capacity – i.e. the better the in-situ condition of substructure – the lower the values of the long-waved fractal range. Consequently, it can be stated that fractal analyses are able to evaluate the condition of the substructure. These evaluations only require vertical track geometry, a measurement signal which is already available to any railway infrastructure manager.

The methodology of fractal analyses of vertical track geometry as also standard deviation of modified track gauge has been implemented until now within the main network of Austrian Federal Railways (ÖBB) and Swiss Federal Railways (SBB). This equals nearly 9000 km of track with time series records dating back more than ten years. Additionally, specific lines in Denmark (Banedanmark), Belgium (InfraBel) and the U.S. (Amtrak) have also already been analysed using this methodology.

3. Measurement Data Aided Asset Management

3.1. Establish Net-Wide Demands

These component-specific figures pose one main question: What is the critical quality for each component? In order to answer this question, we examined around 50 kilometres of track renewal executed between 2012 and 2015. Consequently, it was possible to determine the critical quality of the specific components that lead to a wear-induced component. This makes it possible to spot track sections with one or more components reaching the end of service life. The left side of Figure 6 shows all specific cross sections of the data warehouse as dots in accordance with their sleeper and ballast condition and considering them as directly responsible for track renewal.

A poor condition of substructure is added within the third dimension by colouring the dots brown. The illustration is divided into four areas: *Area I* describes track sections where the sleeper condition has already exceeded the critical condition; *Area II* shows the track sections with no component condition problems; *Area III* displays sections where the ballast condition has already exceeded the critical condition; and *Area IV* illustrates track sections dealing with a poor condition of both sleepers and ballast. Additionally, as a third dimension, the brown dots highlight sections where the substructure condition is poor. Consequently, a component-specific renewal demand can be established for the entire network. On the right hand side, Figure 6

shows that the majority of track sections exhibit either a poor sleeper or a poor ballast condition. This mirrors the aforementioned fact that a superstructure with wooden sleepers must be renewed due to sleeper condition, while the service life of superstructures with concrete sleepers depends on the condition of the ballast. It can also be shown that poor substructure condition only appears with poor ballast condition. This appears logical, since these two components interact very strongly.

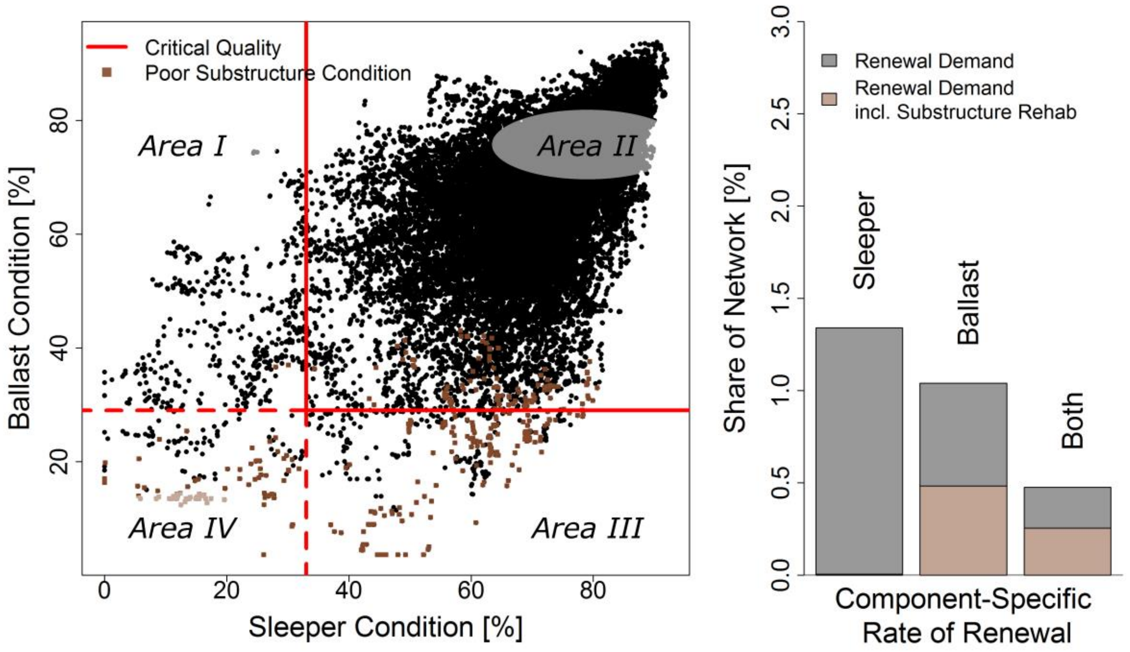

Fig. 6 Deriving net-wide renewal demands for specific components.

This knowledge enables the distinguishing of specific track components which initiate the end of service life. Consequently, the measure which must be implemented can also be determined. For this purpose, the necessity for substructure enhancement in particular is essential information since this can result in a doubling of the renewal costs. The question of whether a component exchange or a total track renewal should be carried out can generally be calculated from the economic perspective. In some cases, it may be a preferable option to execute ballast cleaning separately as the maintenance action. In the great majority of cases a total track renewal is the cheaper solution in terms of Life Cycle Costs.

3.2. Life Cycle Management

The process of life cycle management balances maintenance and renewal within a railway network. The aim is to keep the required track quality for as long as possible by means of effective maintenance measures, but to execute track renewal as soon as it is required. This can be achieved by considering life cycle costs as explained earlier (Fig. 1). The ideal point in time for reinvestment equals the mutual cost-minimum of decreasing depreciation and increasing maintenance. Technically, this point can be defined using the introduced approach of component-specific condition evaluation. This enables determining of the point in time when maintenance no longer makes sense due to the advanced wear of a single or several components. With this crucial input data derived with the presented methodology, the annuity curve (sum of depreciation, maintenance costs and costs of operational hindrances divided by service life) can be calculated for specific track sections. The required input data is asset information such as the age and type of superstructure and output from the present component specific condition evaluation, nothing more.

This allows for determining the ideal point in time for reinvestment not only from a technical, but also from an economic perspective. Owing to net-wide available track measurement data and asset information these calculations can be executed for every track section in order to develop schedule track renewal projects. Fig. 7 illustrates the calculation of the annuity for three different renewal projects. In order to be comparable these projects are based on the same length. The result states that Project 1 and Project 2 show an ideal point for renewal within year X, while for Project 3 the renewal measure should be scheduled two years earlier than this.

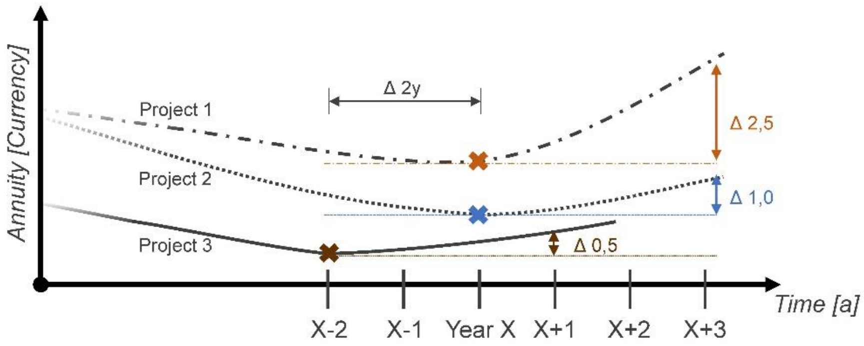

Fig. 7 Evaluation and ranking of renewal projects.

However, this methodology offers another major possibility in addition to calculating the ideal point in time for reinvestment. It enables the increasing of efficiency in times of budget restrictions. As already mentioned Project 1 and Project 2 show the same ideal point of reinvestment in year X.

However, the trend of the annuity is slightly different. While Project 1 is defined with a higher increase of annuity (X+3 = Δ 2.5), Project 2 shows a lower increase (X+3 = Δ 1.0) after year X. This means that the financial damage of not executing the reinvestment at the ideal point in time is much greater in Project 1. Thus, if the budget is inadequate to fund both reinvestments in year X it is crucial to go for Project 1 instead of Project 2. Consequently, the presented methodology not only allows calculation of the ideal point in time for reinvestment but also to rank which projects would result in the biggest damage in the event of non-reinvesting.

4. Summary and Outlook

The presented methodology combines technical assessment with economic considerations using life cycle costs. Evaluating the condition of railway track components, which are the main costs factor, is an essential task. This can be achieved using fractal analyses of vertical track geometry and standard deviation of modified track gauge. These methodologies for track data analyses do not require an additional measurement as the only input data is vertical track geometry and track gauge. The combination of this technical assessment with life cycle cost calculations allows the determining of the ideal point in time for reinvestment of every cross sections within the network. Moreover, the financial damage of non-reinvesting can be quantified. Consequently, this enables the ranking of the importance and financial impact of reinvestment projects. This offers the possibility to minimise financial damage in cases where financial resources are insufficient and the carrying out of every renewal at the ideal point in time.

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