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Track geometry deterioration modelling for asset management: A visual analytics approach

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Abstract

To maintain safe operations and cost-effective maintenance, British railway tracks must be monitored. Track recording assets which include trains and cars, regularly monitor key components of the track in order to detect and diagnose early incipient faults. The measurements accumulate over time, providing time series data that can be used to model track geometry deterioration process. However, the modelling results are often too sophisticated to be used to their full potential in track asset management. As a result, the goal of this research is to use visualisation approaches to display the results of track geometry deterioration, which would simplify and enhance track asset management.

Two visual techniques have been used. The first visual includes two dimensional plots enabling visual fault detection and localisation and the second is a 3D plot which gives a better sight for the decision makers to act. These visual analytics allowed a better understanding of fault occurrence, enable a vast amount of data integration, flexible and simple for stakeholders to use. The limitations of such approaches include the inability to visualise more than 5 dimensions and human interpretation.

Keywords: "Railway, railway infrastructure, track geometry data, railway asset management, decision making, track fault, twist, gauge."

1. Introduction

Quite a significant aspect of the burden of railway maintenance has linkage with track geometry management [1]. Over time, the degradation of the railway is imminent as a result of forces laden on the track by traffic that causes diversions from the horizontal and vertical alignment so designed [2]. The degradation of track geometry to a level that is unacceptable can lead to monumental consequences like derailment which in turn results in interruption of operations, economic loss, damage to the environment and railway asset, as well as the possibility of causing death of passengers and or railway workers [3]. Additionally, degradation of the track geometry usually affects successive loading and track damage. Controlling track degradation featuring the restoration of the geometry conditions of track sessions to an acceptable level are achievable by conducting maintenance actions. Maintenance action scheduling helps in retaining the condition of the geometry or engenders its restoration to its appropriate state in relation to safety limits and comfort. Considering the present technological advancements in railway track geometry, there is the availability of a comprehensive quantity of event data as well as condition monitoring data. These kinds of technologies featuring an advanced predictive analysis offer assurance of predicting the condition of track geometry in line with a strategy for predictive maintenance. Towards ensuring an efficient and effective implementation of maintenance the procedure, railway infrastructure managers have the responsibility of developing resource capacity strategy for addressing the needs for machinery, maintenance time slots, manpower, and other factors. To support the scheduling of maintenance actions, resource availability and operational requirements must be put in place during the execution phase. The mechanism of track geometry degradation is usually a complex one, of which its complexity emanates from the diverse factors affecting it, like the train substructure, the dynamic train loads, environmental conditions, and material properties [4]. Putting the technicality of the degradation process alongside the interaction of this process into consideration, the prediction of effects constituting diverse strategies for maintenance of the condition of the track geometry is a difficult task. In this regard therefore, there is a need for the development of adequate predictive models for tackling essential parts of railway track geometry degradation [5, 6].

The use of predictive models would promote the possibility of making effective decisions for inspection and maintenance planning.

2. Literature review

2.1 Track Geometry Assessment

There are numerous factors that affect degradation. These factors are divided into three categories rolling stock, track, and environs [7]. The following variables affect the degradation process triggered by the interaction between the track and the rolling stock (motors, birdies, and carriages): annual payload having to pass over the track, pace, load factors, steam train traction tries to force, traction brake system compels, wagon braking pressures, and wheel ailment. Highly trafficked tonnage, massive load factors, and high rolling stock pace, as per [8], can generate massive rail flexing stress and strain, which result in more track worsening. The situation of the wheels also contributes to the deterioration of structural parameters. Geometrical flaws in tires (e.g., wheel flats either out) add additional versatile heavy vehicle elements [9].

The building structure circumstances Variants in film thickness all along the path and water contents are useful foundation system metadata that enables a significant relation between track geometry and secondary structural circumstances. The relative humidity suggests whether or not there is a drains issue.

Classification and ballast segment Ballast is an essential element of the structural system that offers track and sleeper elastic assistance. The depth of the ballast and sub-ballast layers must encounter design requirements. The term referring to content suggests whether or not the foul ants restrictions are met. According to [10], maintaining a high path transition requires lateral pressure. This resistance is supplied by contact between the ballast and the rail at the sleeper's foundation, edges (crib), and ends (shoulder). Among the variables that affect lateral stiffness is ballast gradient. For the assessment of the quality of track geometry on the basis of measurement data recorded by inspection trains.

Track geometry quality is mostly assessed by the standard deviation metric which is done by measuring and recording the track geometry for every 25 cm (usually 200 m) over a track section. The standard deviations of the data obtained for all the measurements over a track section are then computed. By employing the three indicators, different track quality indices can be categorized into horizontal and vertical geometry measures. The horizontal geometry measures include alignment and gauge while the vertical geometry measures include longitudinal level, cant and twist. Furthermore, track irregularities can be classified into two parts which are long wavelength irregularities which have a negative effect on the comfort of passengers and the short wavelength irregularities which generate more vibration on axles and wheels.

Andrade and Teixeira [11] used a Bayesian approach to evaluate the degradation of a track geometry model and deal with the uncertainty of its parameters. The track longitudinal level deviation was considered to have a linear relationship with passing tonnage. The initial longitudinal level and degradation rate was also assumed to have a bivariate log-normal prior to distribution. Based on infrastructure features, the track in this the case was divided into four stages which include the design, after the first inspection, between first inspection and first tamping, and between the second and remaining tamping interventions, and the posterior distribution parameters for each stage were calculated. The researchers argue that out of the four stages, parameter uncertainties are most significant in the design stage, hence, degradation prediction and maintenance planning must be done at a logical time after the design stage. One advantage of this model is that the uncertainty of the parameters of the model in the simulation of the degradation process was put into consideration.

Multivariate statistics for modelling railway track geometry deterioration was used by Guler et al. [12], in their study of a segmentation algorithm for breaking the railway track down into homogenous parts. The deterioration rate in twist, level, alignment, gauge and cant was found to be relative to the velocity, curvature, load, sleeper type, rail type, rail length, falling rock, landslide, snow and flood using linear regression. The deterioration was assumed to have occurred in three stage processes. In the first stage, after substantial reconstruction work, the track-bed was allowed to settle, this forms a stabilized phase of stage two after a linear deterioration process was assumed. The last stage is the wear-out period, which is characterized by an increasingly rapid deterioration, this occurs late in the track life. This approach supports that over a long period of time, the track geometry declines linearly.

2.2 Track Geometry Measurement Process

The self-propelled diagnostic vehicle has colluded with MERMEC S.P.A. of Italy to create the Roger 1000, a self-propelled track and aerial contact line imaging vehicle. This was a significant step forward for British railways in its efforts to create a Recording Service of the track geometry towards displaying the derived measurements [13]. Diverse geometry parameters such as alignment, gauge, curve radius, cant, longitudinal level, twist, as well as gradient across a fixed sampling interval are measured by vehicle measures. The data measured are available in three types namely onboard real time reporting, post-processed off-board reporting, and onboard network measurements viewing.

On-board real-time reporting can be employed for addressing serious isolated defects and consists of exceptions reports as well as strip charts. The strip chart is a graphical illustration of the entire track geometry condition in one picture alongside the display of full-course track geometry measurements as well as the subsequent limits of maintenance. There will be the manifestation of a geometry defect in the exceptions report immediately the track geometry measurements surpass the maintenance limits.

Roger 1000 weighs 60 tons and reaches a maximum speed of 160 kilometres per hour once self-propelled (hauled: 200 kilometres per hour). It was created to work at temperatures up from -40 to +40 degrees Celsius. This diagnosing vehicle has ATP (Automatic Train Protection), anti-skid brake pads, power steering, and Location tracking hardware. All were able to operate hardware can be remotely diagnosed using a GSM modem. Roger 1000's helical spring secondary and primary expulsions, as well as active horizontal suspended, allow it to run through curvatures similarly to a commuter train [14].

Roger 1000's primary responsibility is to collect, operate, and hold all kinds of power grid information while also providing related and detailed information to every user community.

All variables are surveyed at 500 mm intervals, and the track recording method is predicated on non-contact measurement techniques. Because of the high degree of automation, railways can handle Roger 1000 with just 2 persons: a person driving and a technologist. When metrics are now being taken on the corresponding record line, it is anticipated that a delegate from the track master will be back on board the track recording machine.

Roger 1000 is a mobile lab that can track and analyse:

• Equipped Track Geometric features
• Vertical lift Contact Line
• Rail Characteristics
• Incorporated Track
• Incorporated Overhead

Following the collection of these data, the very next stages are pre-processing and full mechanism, which are necessary elements of the driving control system. Sensor readings data is converted into data through data processing. The outcomes of measurement techniques are generally available in a so-called "In Office" briefly after they are recorded. It is a piece of software that interprets data on a user-friendly subsystem.

3. Methodology

The appropriate practice for data preparation for track geometry deterioration modelling was harnessed in this study, in line with already, established approaches as closely as possible, although quite a few adjustments are needed to be effected for the suitability of the data so collected. The essence is not to create an advanced method; instead, it is to alter the approaches for the available data. The Fig.1 below denotes the flowchart of the track geometry deterioration modelling methods used in this study.

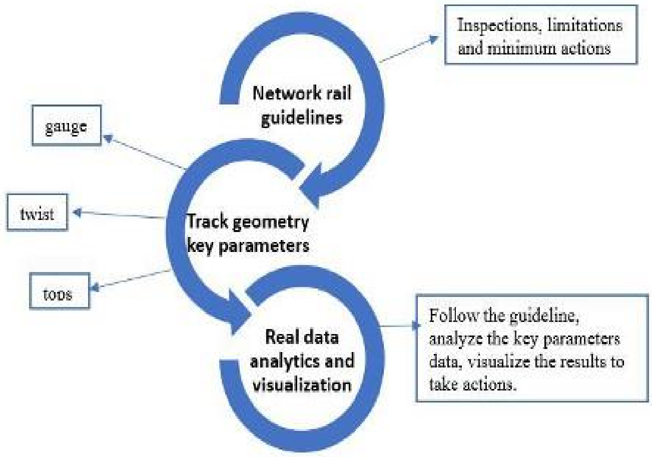

Fig. 1 Methodology Flow Chart

Track geometry data was collected from the measurement train, and the dataset adequately generated. Network rail documents to help connect the dataset with the standards of maintenance, limitations and minimum actions. Datasets focus on the key parameters - gauge, twist and tops, which are the main concerns for maintenance. The whole dataset is about 1GB contains 18 columns and more than 6 million rows. It was acquired monthly by the new measurement train for a specific train route. For better understanding, the dataset was analysed to get an overall understanding. Network rail threshold guidelines were followed in analysing and visualising the data.

Python, R and MATLAB were used in analytics and visualisation process in this study. Thereafter, the twist3m fault was plotted as an example with the location to locate the degradation and see what action can be implemented toward solving the problem. In this process, the limitations are added to the plot to identify the severity of the fault. In the plot, velocity is introduced as a right y-axis to help to see that the train slows the speed in case any problem arises. In preparation of the 3D plot, the dataset is classified into 4 severity categories (good, satisfactory, poor, and very poor) based on the threshold of twist3m fault. The twist, location and severity are plotted as three dimensions so that any impending fault can be located immediately in which mile and yard alongside knowing how severe the fault is.

4. Results and discussions

4.1 2D Representations

The twist fault plot clarifies whether or not there is any trend or irregularity, with the location plotted on the x-axis to locate the problem. Under the twist fault and velocity plot, applying the twist3m threshold to the chart is meant to locate and classify the measurements and to see which category the fault falls into. Moreover, the velocity inclusion as a right y-axis is to discover if there is a relation between reducing the speed and having a fault. In the twist fault with maintenance threshold section, maintenance threshold is added to the previous chart to help with scheduling the maintenance of the track. It is observed here that there is a fault in mile 54 that needs immediate action, and it is under the 36 hours correction category and the twist measurement was just above 25m. Also at the same mile, there is another fault under 14 days' correction band, and twist measurement just above -25m. Furthermore, it can be seen that the speed has slowed down as a result of a fault occurred in mile 54. Then it continues to reduce the speed because there is another issue in mile 57, after that the measurement train has accelerated its speed because there is no other problem after mile 57.

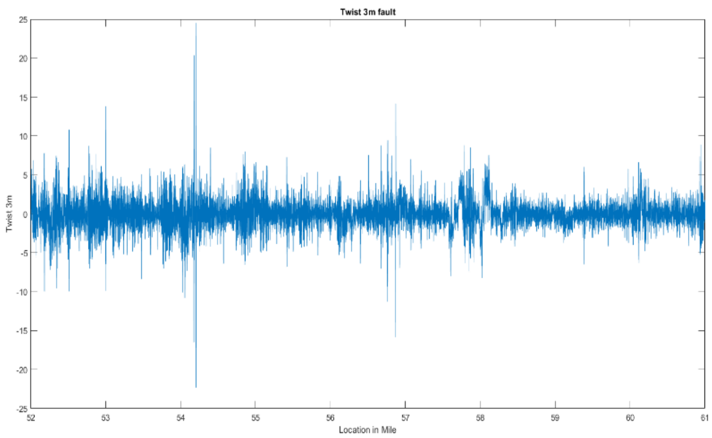

Fig. 2 Section through the twist plot

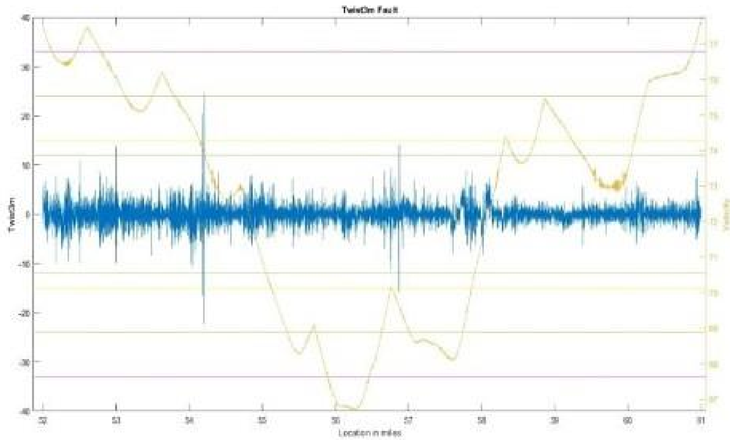

Fig. 3 Section through the twist fault and velocity plot

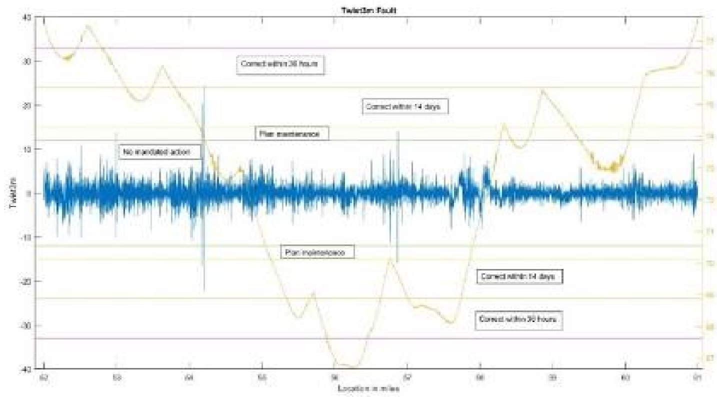

Fig. 4 Section through the Twist fault with maintenance threshold

4.2 3D Representations

The 3D plots depict more interactions and can tend to be more beneficial in taking decision faster than the 2D because as is shown in the graph, the measurements of twist3m were divided into 4 levels of severity (good, satisfactory, poor, very poor). And based on that, decisions can be taken to schedule the maintenance same as it is represented in the 2D plot. The very poor severity can be quickly located because it appears alone and, on the heights, level with a different colour. Furthermore, the main concerns located between mile 54 and 57 can be noticed.

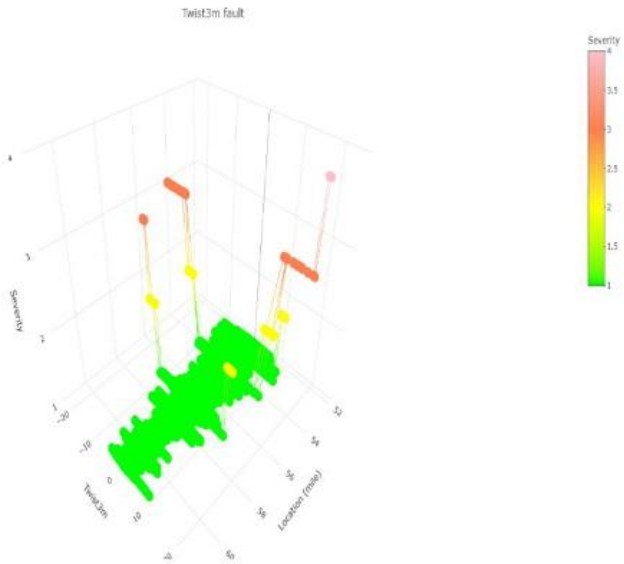

Fig. 5(a): 3D plots for twist fault

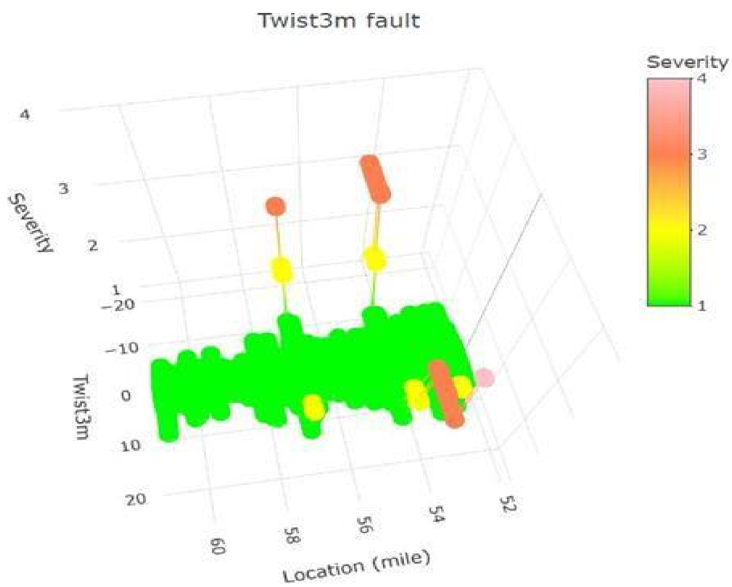

Fig. 5(b): 3D plots for twist fault

5. Conclusion:

The quantification train's railway track data was gathered, and the set of data was properly actually created. Rail companies record to assist in linking the set of data with servicing norms, constraints, and least behaviour. In this research, Python, R, and MATLAB were employed in the data analysis and visual analytics processes. The twist failure plot reveals if or not there is a pattern or abnormality with the spot. 3D plots portray more interaction and may be more useful in making decisions quicker than 2D plots. As classification model, models necessitate a substantial amount of high-quality inspection reports. When track geometry data is inadequate, this model could indeed function.

This model is extremely complicated, making it challenging to perceive. Because of inferences and observation - based prejudices, prediction accuracy may lack theoretical justification and also have poor classification performance.

Researchers frequently ascertain parameters of the model through experimentation and error, which is time-consuming and induces performance of the model to fluctuate from person to person. This study can be more improved in future if accurate data is recorded properly with the passage of time.

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