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Cordel's Approach to Revolutionise the Management of 'Track Geometry' and 'Vehicle Response' Monitoring by Exploiting AI and ML Techniques

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Abstract

Track Geometry measurement regimes used today are typically delivered by dedicated measurement trains and 'attended' systems. Its purpose is to measure track irregularities and drive remedial works to maintain acceptable ride quality and to prevent vehicle derailment risk. It could be argued that the approach is no different to the adopted methods of last century.

Alternative approaches of simpler, cheaper solutions where outputs of vehicle response and correlation to track irregularities have been trialled and studied but have not been adopted. This data, in the opinion of many track engineers, doesn't give enough correlation or information of what the risk is, what work needs to be done to prevent, and by when.

This paper highlights the problems and limitations with the current processes, providing recommendations that Cordel believes are necessary to enhance and streamline the end-to-end management of the track/vehicle system interaction. It fully challenges the status quo, enabling a significant step change in predictive asset management. It discusses introducing a holistic asset management change such as the introduction of an 'asset performance' biassed maintenance approach.

With successful introduction of 'full system' monitoring capabilities, from track irregularity through to car body response, accurately aligned with state-of-the-art data management and AI/ML algorithms, a fully risk managed, predictive asset management regime can be introduced. This will provide efficiencies across the entire industry specifically for stretched maintenance teams with reduced asset access windows.

Keywords: track irregularities, vehicle-track interaction, artificial intelligence, ride comfort, ride quality, car body acceleration, bogie, regional passenger trains, big data, axlebox accelerations, track geometry, vehicle dynamics, asset management.

1 Introduction

Track geometry measurement is undertaken to ensure a safe and smooth, comfortable journey for the passenger and has provided infrastructure managers a way of managing the risk associated with excessive rail deviation from design. The most significant changes to the way geometry variations were recorded was via the introduction of inertial and chord-based measurement systems installed on rail vehicles over 40 years ago. This enabled a very well established 'Means of Control' against derailment risk with accurate, loaded (or dynamic) variations in geometry being measured. However, since then, the methodology in the way geometry is measured and managed hasn't changed significantly in over 20 years.

Despite enhancements in transducer and computation technology, the fundamentals are the same. Taking inertia systems as an example, the systems use optical and inertia transducers to compute a spatial reference of the running rail, and thus measure deviations of those rails within rolling distance boundaries.

Infrastructure managers still utilise attended, dedicated recording cars to measure track irregularity, where data in many cases is processed away from the train in an office environment. The recorded and reported exceedances are then delivered to maintenance teams which drive a work bank of remedial, reactive actions.

The introduction of 'unattended' systems across the world has been a challenge, especially with satisfying coverage, data management and data quality requirements. A key problem area has been linked to managing the volumes of 'repeat' data (and potential repeat exceedance) which occurs when you record over the same sections of track multiple times in short succession.

Geometry measurement and asset management regimes are becoming more and more inefficient, at a time where infrastructure managers are becoming more dependent on them to reduce spiralling costs of renewals and refurbishment works; and industry budgets and maintenance access down times are being challenged and reduced.

Some infrastructure managers have experience in managing unattended systems and have had some success with its deployment. It has been argued by some that this success is because of success being seen on relatively small, simple networks and with the appointment of dedicated data management teams. Despite this, Cordel argue that the fundamental successes seen in managing 'Unattended' systems, provides a good basis with which to evolve at scale.

‘Pseudo’ geometry systems have been suggested to understand geometry risk and many have been trialled internationally. Many research papers provide results of correlations with car-body (ride monitoring) and track irregularities with mixed successes. These types of systems have not successfully been adopted as a method for influencing track asset maintenance. The data is sometimes shown as not being an effective way of highlighting asset risks (i.e. asset managers don't know how to use the outputs or why?).

Cordel proposes a fundamental change to the end-to-end process, fully and effectively exploiting data with the use of proven class leading AI techniques, to significantly reduce data management time and cost. The results will deliver greater insights into asset condition and asset change, effectively highlighting key risk areas to enable efficient, safe and timely asset intervention. The aim is to deliver efficient monitoring solutions where ‘Track Geometry’ and ‘Ride monitoring systems’ can work hand in hand to provide a ‘maintenance regime' to maximise ‘asset performance’ and safety (i.e. Data generated performance threshold limits as well as maintenance tolerance limits based on degradation and risk).

2 Current Challenges

Challenges exist with the end-to-end process of the track geometry measurement regime (and it could be argued all elements of Infrastructure Monitoring). Although the following is taken from a UK perspective, the same challenges are faced by infrastructure managers globally:

2.1 Planning Recording Runs - not recording everywhere

In most countries, dedicated ‘attended’ geometry recording cars are planned to record the majority of running lines at a set frequency. Operational plans incorporate ‘transit’ and ‘record’ sections where vehicles can ‘transit’ to get in ‘position’ and to not ‘over record’ lines (over and above the nominal recording frequency). This provides issues around track access as these trains take up ‘revenue generating’ train paths as well as having qualified technician resources to operate the recording cars.

All too regularly, planned runs do not align to compliance requirements, meaning there are sections of track that are not measured to the ‘nominal’ frequency and to the ‘maximum’ timescales prescribed. By running to set times and frequencies, a robust mechanism for overcoming issues such as the loss of recording is lost. Loss of recording can be because of track access not being available, train crew not available, or where vehicles have mechanical/instrumentation issues. This can result in unknown geometry conditions that can drive additional risk mitigation controls such as speed restrictions and in worst cases a close the line action.

2.2 Dedicated Systems - snapshot view

The nature of planned, dedicated recording, is mainly driven by data analyst resource constraints and obsolete analysis techniques. Existing processes stipulate that data must be reviewed and actioned upon recording. Maintenance teams do not want exceedances and additional reactive work when not expected due to their own resource constraints. This inadvertently drives the dedicated - snapshot ‘find and fix’ process.

2.3 Operation and Live reporting

Track geometry recording vehicles provide ‘real time positioned data’ and are operated by On-Train Technicians to meet the requirements of existing standards; (e.g. *NR/L2/TRK/001_Module 11 - Track geometry - Inspections and minimum actions [1]*), this is to address ‘Immediate Action Faults’ by reporting the fault immediately when detected. This operation requires someone to observe the processed and localised/positioned recorded data in real time. Although real-time reporting is currently an appropriate method to control risks, it contributes to service affecting actions. I.e. The On-Train Technicians can close the line due to a significant ‘valid’ fault or most commonly can close the line due to an incorrectly interpreted ‘invalid’ fault. This second scenario occurs because they are not specifically trained in data quality checks but are more focused on safe running and operation of the vehicle. Both scenario’s cause disruption to the network and heavily impact performance while the issue is investigated and resolved or closed out.

Additional challenges of ‘real time’ reporting are the requirements of accurate train and data positioning and the control of associated network model updates i.e. changes to layouts, linespeeds and track categories on board each vehicle. Recording systems therefore have added complexity to reference and attribute this information to the data ‘live’ to ensure correct reporting.

2.4 Data upload

The data upload process varies between infrastructure managers and their internal requirements. In the UK, each recording run transferred off the train using FTP (File Transfer Protocol) via an onboard Mobile Communication Gateway (the only area that has changed/improved significantly over the years, although comms along the trackside is still quite poor). The data is then manually unpackaged onto a server to be processed with numerous archaic unsupported software tools. It is common that the last recording run of the day is missed as the train is powered off during upload - a critical failing when a turnaround is required for exceedances to be delivered and actioned.

2.5 Data processing – offline

The recorded data (as generated and positioned on-board the train) requires additional quality checks and ‘cleansing' (term used loosely here) steps to be performed offline. This ensures valid data is issued to maintenance teams and for accurate metrics where the data is used for KPI’s as an example.
In the UK specifically, this data processing task is performed manually, and undertaken to ensure correct positional/localisation accuracy and data integrity.

The integrity checks are to ensure the data has been correctly attributed to the right location during recording, and that there are no spurious data points creating invalid exceedances or spurious quality metrics. A manual process to identify outliers, overlays the latest dataset with historic runs using 15-year-old - unsupported software, which was not fit for purpose when it was introduced and is even less so now. Any data attributed to the incorrect line/location or spurious data is invalidated and cannot be recovered. The main risks identified by this process are that invalid data can still be published as the review is very subjective and requires manual entry of where to ‘invalidate to and from’.

The UK is currently working on a 4-5 day turn around on data. Far from ideal when Intervention Limit Faults require action within timescales as little as 7 days!

2.6 Upload into systems

Whilst manual identification of invalid data is being performed, the data is loaded into a Java database developed in the early 2010’s. Rather than develop a robust data requirement specification, the database was built to ingest existing binary (proprietary) formats along with associated .txt files (which encompassed exceedances and standard deviation information) directly from the train. I.e. ingested what was already being output.

This means that the data stored/uploaded is the same as what was recorded at source. The database stores ‘invalidation tables’ associated with any invalidations applied by the analyst. There is no way to easily manipulate, recover or change any of the outputs, especially if any parameters were incorrect or had changed. Any changes to parameters or any changes to thresholds or exceedance information is required to be made to all train software (rather than simply in a back-offline environment).

A PDF copy of the track trace and PDF copies of fault exceedances are the outputs delivered to the maintenance teams from this process. Most recent changes have seen exceedances being presented in an online platform to ease the generation of work orders. This has seen mixed reviews.

A central reporting system provides basic ‘Standard Deviation’ change over time and lists all faults over time. This system is clunky and unsupported internally. It is rarely used other than for providing metrics on total faults per kilometre and ‘Poor Track Geometry’/’Good Track Geometry’’ purposes (i.e. national metrics).

Additional applications to try and improve the visibility of geometry data have been introduced but have created more time-consuming steps in yet ‘another system’ and has highlighted inconsistencies of the data between each of the systems.

There is also no standardised data specification to which applications can work to - i.e. No API (Application Programming Interface) availability.

In the UK, Specific issues arise with the linear reference of miles and yards, with not all miles being consistently 1760 yards. Over time the track has lengthened and shortened due to renewals and maintenance and therefore the UK has a database of each quarter milepost and whether they are ‘long’ or ‘short’. Not to mention the original approach of waymark (Milepost) location was not delivered accurately in the first instance!

Most recently, methods to visualise data history and trending has started, but it has not been seen to deliver expected enhancements to the process. Resulting in them being unable to manage at scale the volume of data already collected - creating clunky and slow responding systems with poor user interface and experience.

2.7 Reactive workload

Finally, after collection, processing and distribution of geometry information, remedial work is required to correct the geometry faults identified. This is all currently based on the output of exceedances from the vehicle - the exceedance report. The exceedances/faults are input manually (or semi-automated) into a work scheduling tool (work bank) after scheduling access and resources appropriately. Although there are pockets of proactive (planned) work tackling emerging faults, a large proportion of work orders are because of developed faults exceeding maintenance tolerances.

This is exasperated by the train recording plan being based on efficient train movements rather than the best approach to collect and handle data. The net result is local maintenance teams being overloaded in a short period of time with actionable faults to address.

Due to the nature of dynamic ‘loaded’ measurements there is marginal variation seen from system to system or more specifically vehicle installation to vehicle installation. Although vehicle dynamics are isolated from the measurements, the effects of the way in which the dynamics and forces are exerted into the rails, will be seen when comparing datasets from the different vehicles. This is a problem with defined limits; where maintenance is tailored to manage the asset to these limits. One vehicle can record and produce a small volume of exceedances, yet a second can produce significantly more. As little as half - to a millimetre difference can cause this jump in the number of actionable faults. This means the maintainer isn't getting a true reflection of the change in condition whilst this phenomenon is occurring. This adds to the existing challenge of resourcing actionable faults in a short period of time even with a known/planned recording pattern.

2.8 Track Irregularity - the only focus

Track Geometry measurement is a measure of the track irregularity. Specific standards in which the track and vehicle must comply to (and allowable deviation in the form of tolerances) have been widely applied across the industry to achieve a safe and comfortable journey. What is not performed routinely is the measure of vehicle response to any given track irregularity. Due to the inefficient nature of dedicated track geometry recording, many infrastructure managers have trilled and performed research into the correlation between geometry faults and 'Pseudo Geometry' systems and/or vehicle response systems. The purpose is to allow a more efficient approach to risk management. These trials have been limited in success, as the results are not fully conclusive, and currently don't allow the track asset manager/maintenance team to plan work from the available data. I.e. The data doesn't give enough information of what the risk is, and what work needs to be done to prevent it, and by when.

It is suggested that 'Pseudo Geometry' can provide a significant understanding of 'risk' at a fraction of the cost. In addition, the advent of newer rolling stock, with technological enhancements in suspension and bogie design, suggests that archaic assumptions on vehicle response to track condition ought to be further investigated. The assumption being that a measure or rather onset of poor vehicle response should drive an 'asset performance' biassed management and maintenance regime, rather than solely focus on track irregularity exceedances.

3 Recommended Approach

An improvement to the whole end to end process, requires an understanding of the strategic approach of each element. Changing one element (collection/processing/reporting/visualisation) would likely result in the need to make changes to another element(s). This has been an issue in the past, each element has only been reviewed and changed in isolation - 'making it fit' into the overall process. Thus, inadvertently increasing the inefficiency in the end-to-end process

The overarching recommendation is to move away from a 'dedicated' find and fix recording plan where data requires detailed human analysis. Cordel proposes to create a solution where data from any source, any train, any platform can be input into, utilise advanced AI analytics and provide a 'real time' view of the asset condition. By introducing vehicle response monitoring and aligning with full EN compliant geometry systems, the outputs widen into a 'system condition view' allowing an enhanced associated risk profile to be generated.

This will allow a more proactive and efficient asset management regime to be implemented where planning and appropriate detailed scoping can be performed enabling more effective works to be planned - when access and resources are more readily available. This will bring much greater efficiencies into an entire organisation and industry, rather than solely focusing on trying to make the track irregularity data collection element the ‘most efficient’ part of the process.
Cordel’s vision is to provide a holistic management suite (Cordel Connect) capable of ingesting multiple geometry recording systems and ride monitoring systems (as well as other monitoring data streams), which continuously monitor the rail corridor - over and above nominal or maximum frequency requirements. This data (along with other data sources) can be seamlessly aligned and will form a base to build analytics and insights into the asset condition, identifying risk and supporting (and/or additional to) current Means of Controls. This means delivering the first genuine ‘Big data’ or ‘system digital twin’ management tool for effective vehicle and track asset condition management.

The key to achieving this vision is by firstly introducing an effective geometry and vehicle response data management solution (under the ‘track connected banner’) to enable a step change from an ‘attended/dedicated measurement’ approach, into a more efficient ‘unattended monitoring’ approach (with an interim capability to allow both). Many of the challenges and risks identified with planning, on train reporting etc are removed just by this step.

In addition to BS EN 13848:2-2006 (Railway applications. Track. Track geometry quality) compliant geometry systems, Cordel also proposes to introduce much more cost effective ‘IMU’ based solutions. These can provide a significant amount of track geometry channels (All vertical profiles) as well as ride quality information (which gives insights into rough ride causes) and allows change detection at much more granular levels. This data requires management in much the same way as full track geometry, in the same platform, to allow it to supplement track geometry recordings. The alignment of vehicle behaviour information will provide insight into the vehicle track interaction and the phenomenon of ‘rough ride’ reporting.
By introducing holistic Edge and AI processing techniques, the issues of subjective, manual processing of data are completely removed. It is proposed that full automation of the data quality assurance process is managed allowing data realignment (if necessary), removal of spurious data and the enhanced data volume allows variability in the data to be seen - yet understood and managed enough to provide true trends.

Modern AI algorithms and systems can easily ingest, process and provide useful analytics and insights into data as specified with no added risk. This can then provide a true degradation model, and the identification of risk sites without the need of reporting exceedances multiple times (if there has been a significant frequency in coverage). With a true ‘live view’ of asset condition, exceedance limits as we know them can be challenged and changed to be a more risk-based approach, using actual degradation rates and risk profiles. Existing empirically derived timescales driving reactive and potentially un-resilient works can be removed and replaced by resilient, efficient and proactive asset management regimes. Thresholds or actions based on a 'performance' limit could be introduced specific to each area, its asset type and or traffic type and patterns. Enhancing the passenger experience by reducing or even removing geometry/response-based service affecting issues.

4 Conclusions and Contributions

To conclude Cordel proposes fully interoperable hardware and software solutions, to achieve the proposed outcomes of this paper, and suggest the industry approach to current Track Geometry management is challenged.

It has been suggested that benefits across the entire end-end track asset management regime can be introduced because of a novel approach to data capture and data management. By increasing the frequency of data collection and management accordingly, an accurate view of asset risk can be more accurately predicted and visualised for preventative maintenance activities to be planned.

To achieve this, the exploitation of Machine Learning and AI techniques and enhanced computation power available today is required. Methodologies of autonomous data ingestion, data alignment and data cleansing need to be focused on, enabling large datasets to be exploited and used to inform future data regimes. This approach will allow scalability of additional capture and further refine degradation and risk models applied. By applying advanced analytics onto track geometry and additional ride monitoring sensor data, real time safety and performance metrics can be produced, allowing decision making to focus across the system: i.e. are planned works required to enhance passenger experience for the infrastructure or vehicle (or both)?

Granular, frequent data capture will enable an accurate risk profile to be created, delivering efficiencies in asset and vehicle maintenance to align maintenance when access and resources are available. Additionally, by providing vehicle/track interaction outputs, it enables the industry to deliver key objectives of automated inspection regimes and passenger satisfaction, through increased asset availability and improved ride quality. Although more equipment and sensors can potentially be an increase in capital funding, over the whole life cycle, time and cost can be saved from procurement of bespoke system and vehicles, route and vehicle planning, vehicle and system maintenance, data cleansing and asset maintenance. This is more sustainable, reduces the carbon footprint and allows an open opportunity for third party SME's to deliver meaningful data to the industry. The key achievement is to provide analysis of data that directly influences future maintenance planning.

References

[1] Network Rail, NR/L2/TRK/001_Module 11 - Track geometry - Inspections and minimum actions, 2022