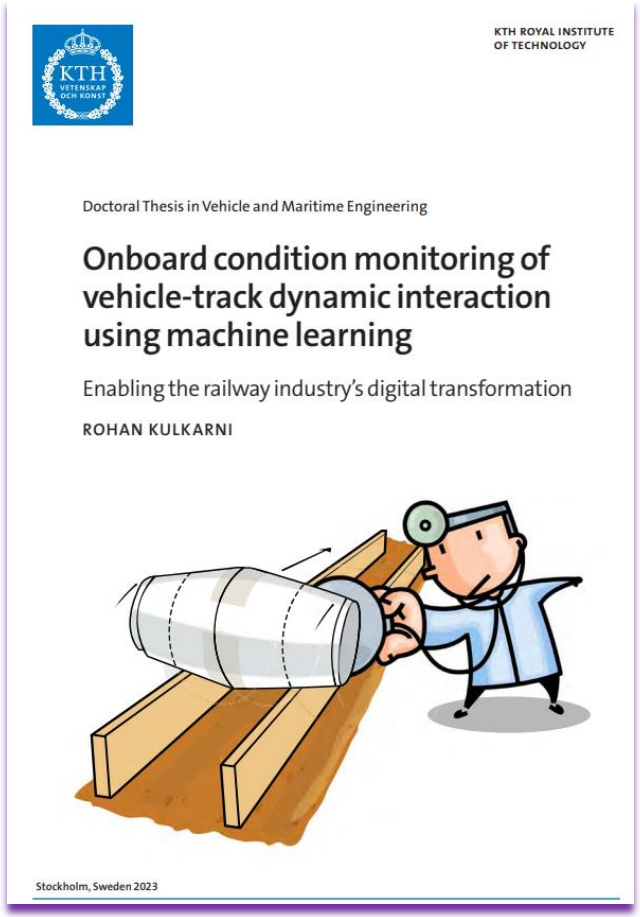
Excellens järnväg resultatkonferens

Martin Li
Underhåll / Teknik och Miljö / Spårsystem (UHtsp1)
martin.li@trafikverket.se

Fordonsbaserad tillståndsövervakning av dynamisk samverkan fordon-bana



KTH ROYAL INSTITUTE OF TECHNOLOGY

Doctoral Thesis in Vehicle and Maritime Engineering

Onboard condition monitoring of vehicle-track dynamic interaction using machine learning

Enabling the railway industry's digital transformation

ROHAN KULKARNI

Stockholm, Sweden 2023

iVRIDA-Fleet: Unsupervised rail vehicle running instability detection algorithm for passenger vehicle fleet

Rohan Kulkarni[a,*], Mats Berg[a], Alireza Qazizadeh[a], Pär Söderström[b], Hugh Wheelwright[c], David Vincent[c] and Martin Li[d]

[a]Engineering Mechanics Department, KTH Royal Institute of Technology, Stockholm, 100 44, Sweden
[b]SJ AB, Stockholm, 111 20, Sweden
[c]Hitachi Rail Limited, Hampshire, SO50 9NW, United Kingdom
[d]Swedish Transport Administration, Göteborg, Sweden

ARTICLE INFO

Keywords:
Vehicle hunting
unsupervised machine learning
Autoencoder
worn wheel
worn rail
vehicle fleet

ABSTRACT

Identifying faults contributing to unsafe conditions, such as a high-speed rail vehicle running instability, is crucial to ensuring operational safety. But the occurrence of vehicle running instability during regular operation across the whole vehicle fleet is a rare anomaly. An unsupervised anomaly detection (AD) based *iVRIDA-fleet* framework is therefore proposed to detect vehicle running instability and identify its root cause. The performance of Principal Component Analysis (PCA-AD, baseline model), Sparse Autoencoder (SAE-AD), and LSTM Encoder Decoder (LSTMEncDec-AD) models are evaluated to detect the occurrence of vehicle running instability. A k-means algorithm is then applied to latent space representations to identify various clusters associated with different root causes of observed vehicle running instability. The effectiveness of the proposed *iVRIDA-fleet* framework is demonstrated using onboard accelerations measured on a Swedish X2000 vehicle fleet. The probability of vehicle running instability occurrence is observed to be only 0.35% of onboard accelerations corresponding to 827,467 km travel distance.

Furthermore, the root causes identified by the *iVRIDA-fleet* framework are validated by investigating the maintenance records of the vehicles and track. It is identified that heavily worn wheels were the primary root cause of observed vehicle running instability, but the track (actual gauge and rail profiles) was also a contributing factor. The proposed algorithm contributes towards the digitalisation of vehicle and track maintenance by intelligently identifying anomalous events of the vehicle-track dynamic interaction.

1. Introduction

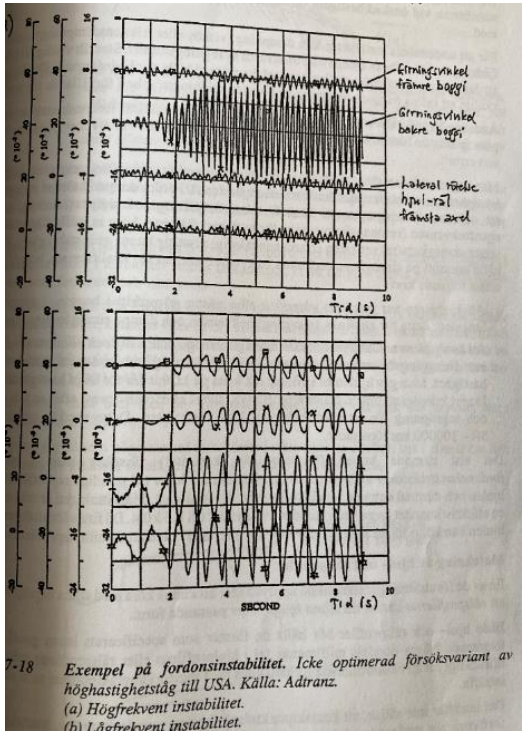
The self-excited oscillation of wheelsets, running gears, or the whole rail vehicle in the lateral direction is defined as running instability. The running instabilities associated with wheelset, bogie and vehicle is called wheelset running instability, bogie running instability and vehicle running instability, respectively. Vehicle running instability is an inherent phenomenon in vehicle-track dynamic interaction and typically appears at a high vehicle speed, on a straight track, or in large-radius curves. Running instability is thus an intrinsic behaviour of a vehicle-track system that depends on the health of the vehicle and track subsystems. The foremost root causes for running instability are poor vehicle yaw dampers, too soft primary suspension in the horizontal plane, or poor wheel-rail interface geometry (including actual track gauge). Running instability is both a safety concern and can also cause passenger discomfort [1]. The EN 14363:2016+A1 [2] and FRA [3] standards specify the methods to diagnose the occurrence of vehicle running instability in the certification phase. However, these methods cannot detect the root causes of the observed running instability. Therefore, many recent articles focus on proposing methodologies for detecting vehicle instability and identifying root causes. The methods described in [4, 5, 6, 7, 8, 9] are physical model-based methods. Operational Modal Analysis (OMA) and spectral analysis-based methods are proposed in [4, 5] and [6, 7, 8, 9], respectively, to detect vehicle running instability. In more recent years, various researchers [10, 11, 12, 13, 14, 15, 16, 17, 18] presented purely data-driven methods for diagnosis of vehicle running instability. These algorithms are typical supervised data-driven methods. However, supervised models have drawbacks when it comes to deploying, continuously training, and updating supervised classifiers on measurements. The challenges include a lack of labelled datasets [19], drift in datasets because of varied operating conditions [20], and poor-quality data. The authors proposed the *iVRIDA* (intelligent Vehicle Running Instability Detection Algorithm) [21] algorithm to address these challenges; the algorithm can learn from partial or wholly unlabelled data. The *iVRIDA* algorithm is a signal reconstruction-based anomaly detection (AD) algorithm. The AD model is trained with data from a healthy system to learn the healthy system behaviour. Subsequently, the model is deployed on a data stream to identify unhealthy incidences significantly different from healthy systems. In [22] a similar approach based on Variational Deep Convolutional Generative Adversarial Network (DCVAE-GAN) is proposed which exhibits the benefit of generative methods for vehicle running instability detection of high-speed trains.

*Corresponding author
rohank@kth.se (R. Kulkarni)
ORCID(s): 0000-0001-5644-248X (R. Kulkarni)

Rohan Kulkarni's Ph. D. thesis and Paper F

Gånginstabilitet: problem - orsak - konsekvens - säkerhet

X55 fick instabilitetsproblem i Hallandsås tunneln (2017)



7-18 *Exempel på fordonsinstabilitet. Icke optimerad försöksvariant av höghastighetståg till USA. Källa: Adtranz.*
(a) Högfrekvent instabilitet.
(b) Lågfrekvent instabilitet.

Hög- respektive lågfrekvent instabilitet (KTH, Spårfordonsdynamik, 2000)

Skadad spårkomponent och försämrat spårläge

En känd bild från Polach (2005)

TRAFIKVERKET

Fordonsbaserad tillståndsövervakning behövs

- **KTHs bidrag: *iVRIDA-Fleet***
  - *”This thesis proposes an unsupervised anomaly detection (AD) framework, referred to as iVRIDA, which utilizes carbody acceleration for vehicle running instability detections (VRID). The iVRIDA framework is tested and validated in two independent investigations based on onboard measurements of two high-speed vehicles operating in Europa. Additionally, the iVRIDA framework is extended into iVRIDA-fleet for the proposed framework’s fleetwide application”*

    Rohan Kulkarni, Ph.D. thesis, KTH, (2023)

- **Hur ska *iVRIDA-Fleet* implementeras?**
  - *”Det här är ett utmärkt exempel på Triple Helix-arbete där myndigheter, industrin och akademin samverkar för att öka vår kunskap i syfte att utveckla nya behovsdrivna lösningar för ett excellent transportsystem. Som deltagare i forskningsprogrammen både bidrar vi och drar nytta av målsättningen att stärka industrin, skapa jobb och att utveckla ett hållbart, sammanlänkat europeiskt järnvägssystem”*

    Bo Olsson, programansvarig för EU-Rail och Shift2Rail i Trafikverket, om ett forskningsarbete av Trafikverket, SJ, KTH och andra parterna i samma område