Draft Print | v.0.6

Continuous Pre-Risk Intelligent Category Space (C-PRICS)

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Executive Summary

Continuous Pre-Risk Intelligent Category Space (C-PRICS) is a machine learning-based framework for early detection and continuous monitoring of cyclic top[1] defects in railway tracks. Unlike traditional threshold-based detection systems, C-PRICS employs continuous monitoring and feature-based analysis to identify emerging patterns before they reach critical levels.

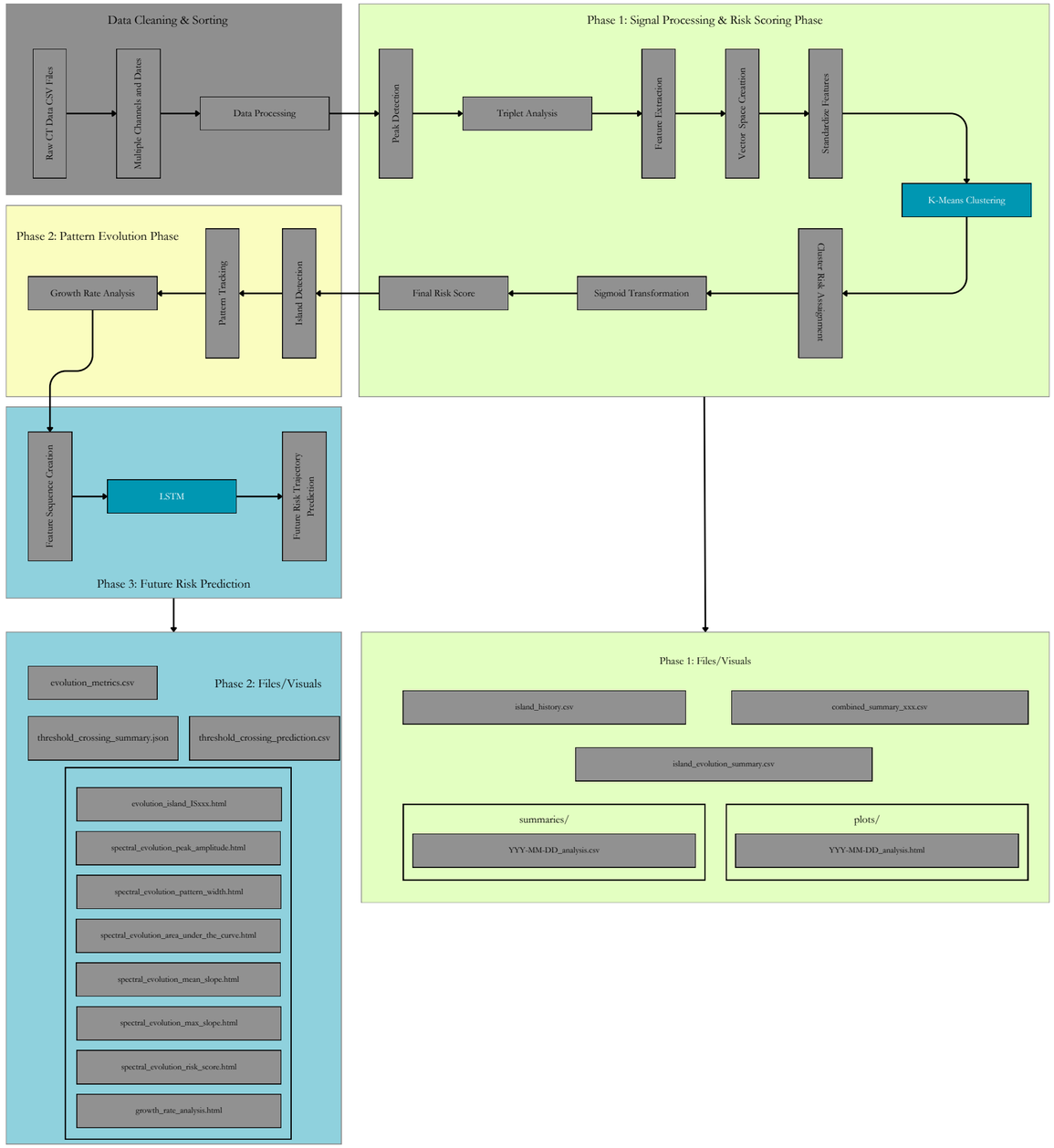
Network Rail's flagship product, *Insight*, employs a binary threshold-based detection system for cyclic tops that presents, at least, two critical limitations:

Sudden Risk Transitions	Limited Pattern Recognition
A track section can abruptly change from "safe" to "high-risk" when a single peak emerges between existing peaks, triggering the cyclic top detection threshold.	Current systems don't account for the spatial and temporal evolution of track geometry patterns.

As demonstrated in detail in *Figure 1,* C-PRICS addresses these limitations through a three-phase approach: (1) Signal Processing and Feature Extraction Phase, (2) Pattern Evolution Analysis Phase, (3) LSTM Predictive Analytics.

[1] Cyclic top, a progressive rail track defect where a series of dips form due to vehicle impact loading, can lead to increased vertical oscillations and potential derailment, especially for freight trains with specific suspension characteristics.

Figure 1: C-PRICS Project Pipeline. The blue boxes, representing K-Means Clustering and LSTM, highlight the points where both unsupervised and supervised Machine Learning techniques were employed.



[1] C-PRICS Solution Framework

C-PRICS Solution Framework addresses these limitations through a three-tiered approach:

Problem	Technical Solution	Implementation Details	Outcome
Sudden Risk Transitions: - Binary threshold detection - Abrupt safe-to-critical jumps - Missed early warning signs	Signal Processing & Feature Extraction - Triplet peak analysis - Cubic spline interpolation - K-means clustering	- Detects consecutive peak formations using sliding window analysis - Extracts features: • Pattern width • Peak amplitude • Area under curve • Mean/max slopes - Clusters feature vectors for risk categorization	- Continuous risk scoring replacing binary classification - Early pattern detection - Feature-based risk assessment - Granular defect characterization
Limited Pattern Recognition: - Limited temporal tracking - Missed pattern evolution - Isolated defect analysis	Pattern Evolution Analysis - Island tracking algorithm - Spatial-temporal correlation - Exponential growth modelling	- Tracks pattern 'islands' using: • Distance thresholds • Overlap analysis - Calculates: • Growth rates • Pattern merging/splitting • Location drift	- Quantified evolution rates - Pattern propagation tracking - Deterioration acceleration detection - Spatial correlation mapping
No Predictive Capability: - Reactive maintenance - Undefined risk trajectories - Uncertain intervention timing	LSTM Predictive Analytics - Sequence modelling - Multi-layer LSTM architecture - Threshold crossing prediction	- Processes feature sequences - Predicts 90-day risk trajectories - Calculates: • Risk velocities • Risk acceleration • Crossing probabilities	- Data-driven prediction - Optimized maintenance timing - Proactive intervention planning - Risk trajectory forecasting

C-PRICS contributes to Insights team's core mantra of moving from a reactive to a proactive modus operandi. While it addresses the fundamental limitations of current detection methods, one of its core innovations is providing quantifiable metrics for maintenance decisions.

Next Steps

To test and develop a set of performance metrics, such as accuracy, precision, and others, for the C-PRICS framework. This will be carried out in a controlled environment, where we already know the expected outcome.

There are some bug, related to the prediction display stemming from LSTM. The bug prevents the display of the predicted date when a defect will reach 0.9 and 1.0, although this information is present in the CSV file.