TRA
TRANSPORT RESEARCH ARENA BUDAPEST
18-21/05/26

Life cycle cost analysis of railway track sections using look-up tables

Abderrahman Ait-Ali (VTI & LiU)

Co-authors: K. Odolinski, E. From, J. Leung, P. Torstensson, A. Nissen, P-O Larsson-Kraik, S. Stichel

18/05/2026
Transport Research Arena 2026 | Budapest

Introduction

Background and objectives

Background

- Heavy-haul railway assets are under growing pressure
  - **Higher demand**
  - **Ageing infrastructure**
  - **Increasing wear & rolling contact fatigue (RCF)**

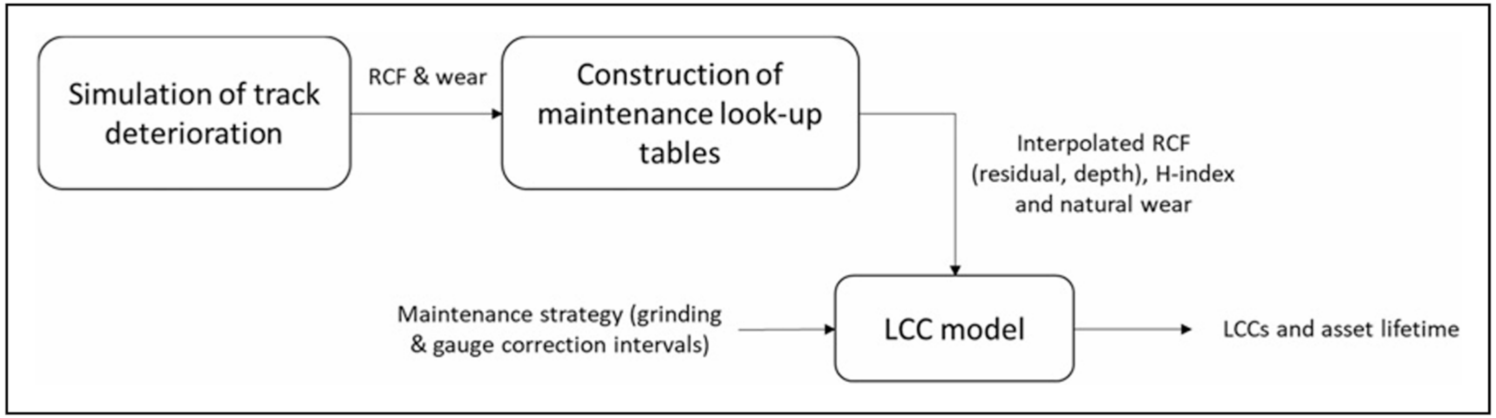
Low rail RCF damage on a curve (H-Nia et al, 2023)

- Account for additional costs
  - **Consequences of downtime (closing tracks for maintenance/renewals).**
  - **Need to capture environmental impacts and circularity benefits (rail reuse/recycling).**

- Planning across different tracks/geometries
  - **Infrastructure managers coordinate adjacent curves and tangents together.**
  - **Shared possessions affect less the total cost.**

Objectives

- From a validated rail-level optimization (Ait-Ali et al, 2025) to a section-level planning.



Combination of track-deterioration simulations and LCC modelling using maintenance look-up tables (Ait-Ali et al, 2025).

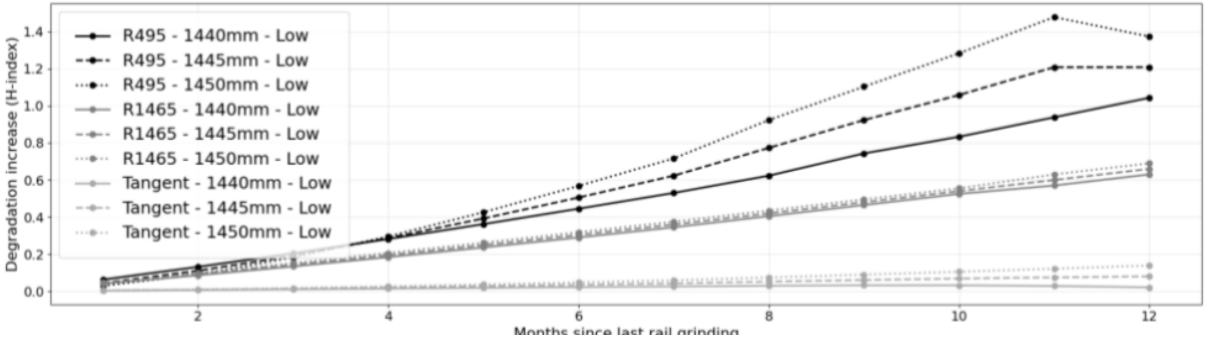
- Build a scalable framework that minimizes section-level equivalent annual cost using
  - **Simulation-based look-up tables**
  - **Life cycle cost analysis (LCCA)**
  - **Environmental costs, and circularity**

Model

Framework & contributions

Framework overview

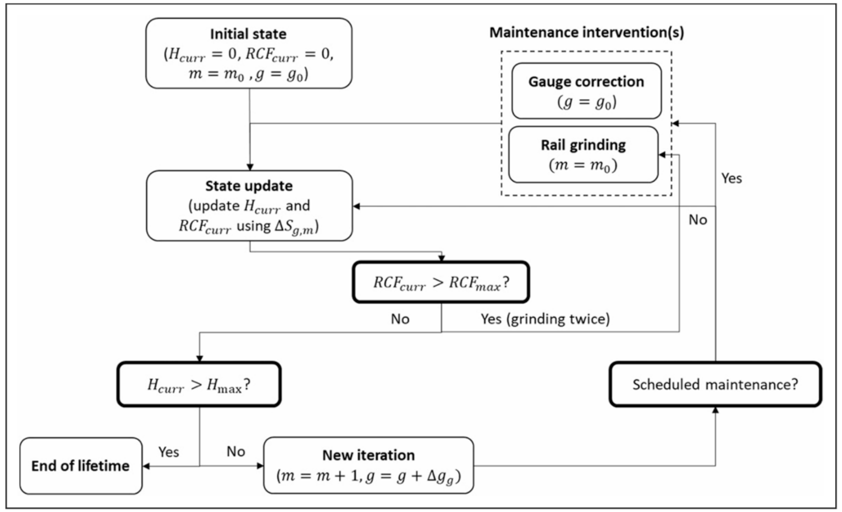
- Traffic conditions & geometries matter, e.g.,
  - **Curve radius, rail profile**
  - **Axle loads**



Degradation increase (H-index) of low rails over time since the last grinding for tangent track and curves with radii of 495 m and 1465 m at different gauges.

- Engineering simulations generate look-up tables that describe degradation states for
  - **Wear & RCF**
  - **H-index (vertical and lateral degradation)**

- Look-up tables replace repeated (expensive) simulations
  - **Degradation states**
  - **Different grinding and gauge correction events**



Procedure for determining the rail lifetime and calculating the LCCs for a given maintenance strategy (Ait-Ali et al, 2025)

Main contributions

- Model extension
  - **Initial basic model at the single rail level**
  - **Extension of the optimization to adjacent track section with shared possessions**

- Life cycle cost analysis (LCCA)
  - **Maintenance and renewal costs (labour and material)**
  - **Possession costs (downtime)**
  - **Environmental costs & circularity (reuse/recycling of rail)**

- Track and section-level optimization
  - **Optimal maintenance and renewal plans**
  - **Shared possessions across adjacent tracks**

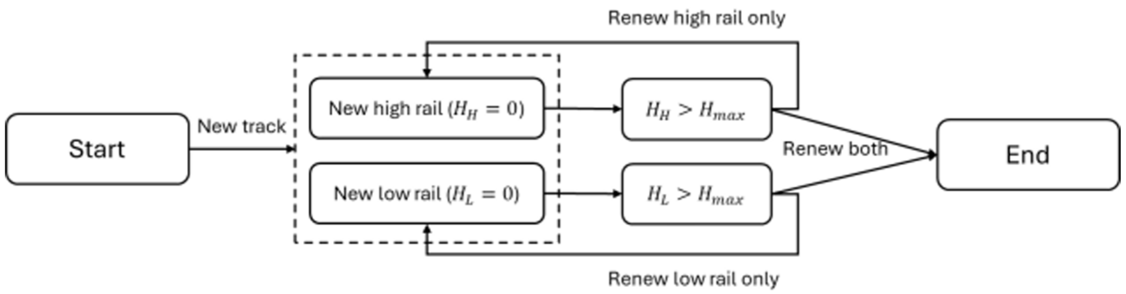


Illustration of the joint analysis of both outer (high) and inner (low) rail (Leung et al, 2025)

Case study

Data and preliminary results

Public domain, via Wikimedia Commons

Iron Ore Line in Northern Sweden

- 400 km **single track** line used to transport iron ore from mines in *Kiruna* (*Svappavaara*, Gällivare and *Malmberget)* to the ports of *Narvik* (and *Luleå).*
- In 2020, the Iron ore line carried over 37 million tones of goods corresponding to approximately **20 % of the entire freight transport** in Sweden.
- The total train weight is up to 9 400 tones. The maximum permissible **axle load is 32.5 tonnes**
- The traffic operated by *LKAB*
    - **typically consists of 67 freight cars**
    - **hauled by IORE locomotives.**

Kabelleger / David Gubler (http://www.bahnbilder.ch) - Own work: http://www.bahnbilder.ch/picture/3324

Data

Key input	Value
Annual traffic load	35 MGT
Maximum axle load	32.5 t
Rail hardness	350 HT
Gauge correction interval	48 months
Discount rate	4%
Capacity possession cost	50,293 SEK/h

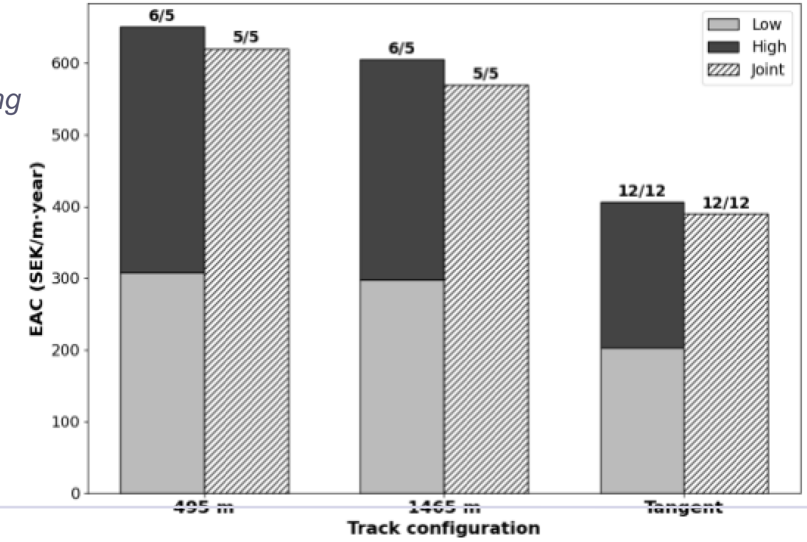
Studied section composed of three adjacent 1-km tracks with different geometries.

Track	Radius (in m)	Average gauge widening (mm/year)	High rail	Low rail
1	495	2	MB1	MB6
2	1465	1.5	MB4	MB4
3	∞ (tangent)	1	MB4	MB4

- Purpose
    - **Compare track-level and section-level optimization under realistic heavy-haul conditions.**

Results

- At the single rail level (low/high)
  - **Optimal grinding intervals are 6/5 months (low/high) for both curves and 12/12 months for tangent track.**
  - **The tight 495 m curve has the highest costs.**
- At the track level
  - **Optimal intervals are 5 months for both curves and 12 months for tangent track.**
  - **Joint optimization at the track level cuts costs by about 4-6%.**
- Coordinated solution at the section level
  - **Optimal intervals are 6-month grinding on both curved tracks; and annual grinding on tangent track.**
  - **Optimization at the section level cuts costs further through shared grinding possessions across tracks.**



Optimal annuities for the low rail, high rail, and whole track. Labels above bars show the optimal grinding intervals (months) for low/high rails.

Schematic annual intervention pattern for the optimized three-track section.

Conclusions

Implications & next steps

Implications

- For infrastructure managers
    - **Use LCC-optimized maintenance and renewal plans.**
    - **Bundle interventions to lower possession-related losses.**
    - **Support maintenance contract design and procurement.**

- For sustainability and circularity
    - **Environmental impacts (of maintenance and renewals) are built into the LCCA.**
    - **Circularity coefficient credits reuse and recycling in renewals.**

Next steps

- Main take-away
  - **The framework turns detailed degradation modeling into a scalable decision-support.**
  - **The tool can be used for coordinated, more resource-efficient maintenance planning.**

- Future work
  - **Scale to larger contract areas with more standard elements.**
  - **Integrate delay costs and historical grinding data.**
  - **Benchmark against current practice and test sensitivity to key assumptions.**

Thank you

Questions?

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Re-Generation in transport

abderrahman.ait.ali@vti.se