Track Service Life
Driven by Ballast Quality

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System Approach

→ the whole track must be considered to evaluate one component, as the one component acts within the system.
An integrative approach for track quality:

A good track behaves well, a bad one deteriorates faster.

The track deterioration depends on the current quality level.

Differential equation: \( \frac{\Delta Q}{Q} = \text{const.} \)

\[
Q(t) = Q_0 \times e^{bt}
\]

Initial quality delivered by Investment

Track deterioration fought by Maintenance
In the following long term behaviour is discussed based on the e-function.
Primary target is the support of LCC based strategies in demonstrating its economic benefits (including costs of operational hindrances).

- The whole life span of track must be considered → LifeCycleCosting
- Cost consequences of track quality must be considered → COH

Graph showing track quality over service life with investment, maintenance, and critical track quality indicators.
The aim of any track strategy is to reduce total costs of superstructure.

Knowing the cost distribution (straight section, high loaded line) assumptions can be made:

1. Depreciation is the dominating cost fraction (re-investment cost/service life)
2. Costs of Operational Hindrances (COH) can be quite high
3. Maintenance costs reach some 25% in maximum (in straight sections)

All these cost proportions have interactions and therefore cannot be treaded separately!
Track Quality Behaviour

\[ Q = Q_0 e^{bt} \]

- **Q** represents the decreasing track quality.
- **Q₀** is the initial track quality.
- **b** is the rate constant.
- **t** is time.
The better the initial quality the less the maintenance demand.
Track Quality Behaviour

\[ Q = Q_0 e^{bt} \]

- **Q** = track quality
- **Q_0** = initial track quality
- **b** = rate of decrease
- **t** = time

- **QIH** = intervention level
- **QES** = end of service

Renewal

Time

descending track quality
Just maintenance *solving* problems is sustainable.
Looking homogeneous sections of one parameter set should result in the same track behaviour.

Nothing special - just a drainage problem.

Quelle: Diss. J. Holzfeind
Source of Input Data

Technical Evaluation

Regression model based on MDZ-A value or standard deviation every 5 meters

- Measured data since 2000
- 3,800 km continuous track data including almost the whole main network of the Austrian Federal Railways

\[ Q(t) = Q_n \times e^{b_n t} \]
### Behaviour of Track Section

#### Characteristics of the Standard Kilometre

<table>
<thead>
<tr>
<th>Good Subsoil Conditions</th>
<th>400&lt;R&lt;600</th>
<th>Double Track</th>
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<tr>
<td>Gross Tons/day and Track</td>
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<td>600 kg</td>
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<tr>
<td>Sleeper</td>
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| Life Span | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
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| Levelling-Lining-Tamping | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |
| Spare Part Exchange |   |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Rail Grinding |   |   |   |   |   |   |   |   |   |   |    |    | 1  |    |    |    |    |    |    |    |    |    |    |    |
| Rail Exchange |   |   |   |   |   |   |   |   |   |   |    | 0,3|    |    |    |    |    |    |    |    |    |    |    |    |
| Joint Maintenance |   |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Rail Pad Exchange |   |   |   |   |   |   |   |   |   |   |    |    | 1  |    |    |    |    |    |    |    |    |    |    |    |
| Spot Repair | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1,5 | 1,5 | 1,5 | 1,5 | 1,5 | 1,5 |

#### Calculating of all track work given in the working cycle including their costs of operational hindrances → LIFE CYCLE COSTS

- Investment
- Service Life
- Planned Maintenance
- Small Maintenance (reactive)
Life Cycle Costing

track section → life cycle costs → investment and maintenance strategy

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evaluation principle (5% net rate of interest): minimum of dynamic average annual costs including costs of operational hindrances
Research: Analysis of b-rates under various boundary conditions

Prognosis: From the past into the past from the past into the present from the present into the future

The intervention level is stricter at the beginning! Slow order!

Due to ballast wear the b-rate rises.
The tamping interval shrinks; at the end: more than one tamping a year.

1. Intervention level, deterioration rate and reachable quality (Q and b) show a stable correlation.
2. Prognosis of track alignment and therefore also tamping demand is possible.
In this case:
The ballast is the limiting element for the service life!
Cosequences of Ballast Wear

Polluted ballast bed $\rightarrow$ missing elasticity (breaking); inefficient drainage

Vertical alignment failures $\rightarrow$ single failures

Concrete sleepers:
Rail pads: high wear $\rightarrow$ rail foot is pressed into the concrete, parts are chipped (rail inclination signal)

Traffic load (flexing) and frequent tamping $\rightarrow$ wear of sleeper edges (round edges $\rightarrow$ stability)

Wooden sleepers:
Natural wear $\rightarrow$ Rotting (transmission power)

Pressed-in ribbed plates $\rightarrow$ Shearing, Transmission power (gauge, rail inclination signal)
Example
Options to better the situation

A working drainage system and a load bearing subsoil is assumed.

There are at least two preventive possibilities to better the situation and extent service life and to prolongate maintenance demand:

1. **Increase ballast quality**

   Use of basalt or granite and not weak limestone ballast

   Soft limestone compared to granite:
   - Reduction of 20% track service life
   - Reduction of 33% turnout service life

2. **Reduce forces in ballast**

   Use of under sleeper pads
Investment Strategy

1. Higher quality of materials
   Concrete sleepers with Under Sleeper Pads (USP)
Under Sleeper Pads

contact areas sleeper - ballast after tamping

with Under Sleeper Pads (USP) up to 35%

3% to 5% after tamping

9% after tamping and stabilizing

before tamping up to max. 12%
Under Sleeper Pads

Reference track: 60E1 rails CW on concrete mono bloc sleepers

1484 sections behaved like this
But 16 did not…?
12 section had no USP and 4 section showed very poor sub soil
Input Data due to 1500 Sections

Actual Data Set

Sleeper price + 30%

initial quality increased by 18% proven
b-rate reduced by 63% proven
prolongation of tamping cycle by the factor of 2.75 proven
prolongation of service life + 38% calculated (limited to maximum 50 years)

All comments reflect a required internal rate of return of real 5%.

Note:
In general concrete sleepers are not in use at lines carrying less than 10,000 gross tons per day.
Basic Results

Internal Rate of Return (IRR) for Under Sleeper Pads

Assuming a required internal rate of return of real 5% USP can be proposed independently from the transport volume. However, the higher the transport volume, the higher the benefits.
Basic Results

Track

- **Average Annual Costs**
- **Depreciation**
- **Costs of Operational Hindrances**
- **Costs of Maintenance**

**IRR up to 20% for high loaded sections**
The economic efficiency increases with decreasing investment and increasing traffic load. However, the internal rate of return shows positive results in any case even independent from the traffic load.
The evaluation shows that less technical effects on tamping (prolongation of tamping cycle by the factor 2 instead of 2.75) and the service life (prolongation of 20 per cent instead of 38 per cent) influences the results marginal. However, if service life could not be prolonged at all, USP can be proposed for lines carrying more than 12,000 gross tons per day, only.
Summary

Due to the basic evaluation every concrete sleeper should be equipped with USP, independently from the transport volume on the line.
Outlook

*Further researches in the next two years at the Institute of Railway Engineering and Transport Economy will be done:*

Laboratory test to measure the initial and long term settlement behaviour of five different ballast types using sleepers with and without under sleeper pads.

Measuring the load distribution magnitudes under the ballast bed during the tests.

Determining the material wear after the testing cycle.
Thank you for your attention!

DI Armin Berghold
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Back-Up
Under Sleeper Pads

Track

Average Annual Costs
Depreciation
Costs of Operational Hindrances
Costs of Maintenance

100%

68%

additional investment in initial quality pays back
The quality figure MDZ describes the differences of accelerations in a fictive car caused by the geometry of track. The higher these differences the worse the riding quality.

As failures in all directions (x-, y-, z) cause accelerations, the figure automatically sums up these influences by the physical laws.

\[
MDZ = v^{0.65} * \frac{1}{L} \sum_{0}^{L} \text{Diff} \cdot \sqrt{v^2 + (h + \Delta^2 i)^2}
\]

As this quality figure is speed dependent it allows calculating the acceptable speed possible for a certain real track quality. Moreover it allows comparing line quality with different speeds based on a given riding quality.
Basic Strategy
Permanent Slow Orders
Minimized Maintenance
Permanent Component Exchange

Different Strategies
(160 Trains per Day and Track)
Technical and LCC Approach

Calculation of e-functions for quality behaviour

Decrease of track quality

Track work  Quality behaviour