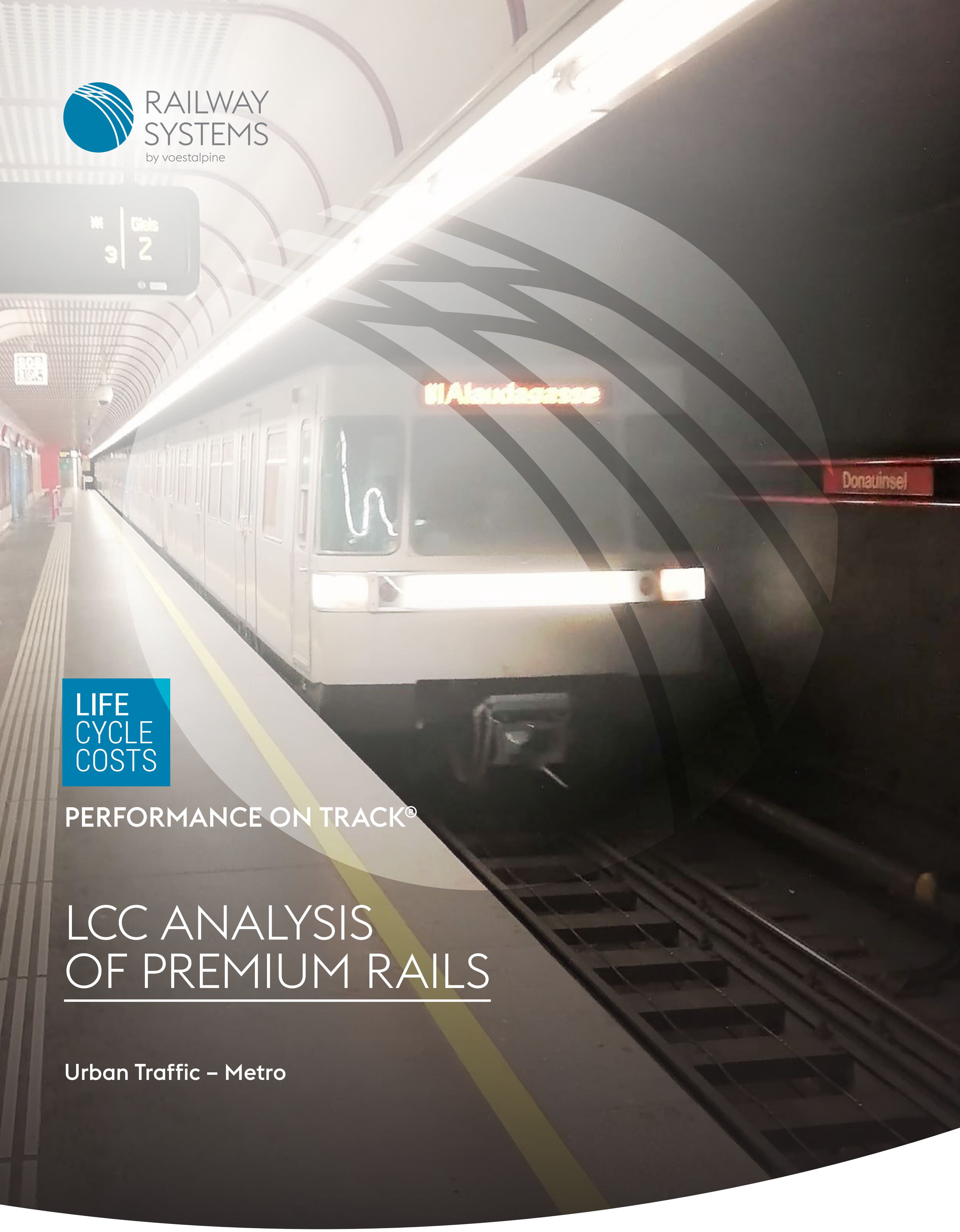
RAILWAY
SYSTEMS
by voestalpine



LIFE
CYCLE
COSTS

PERFORMANCE ON TRACK®

LCC ANALYSIS OF PREMIUM RAILS

Urban Traffic – Metro

voestalpine Rail Technology GmbH
www.voestalpine.com/railway-systems

voestalpine
ONE STEP AHEAD.

LCC ANALYSIS OF PREMIUM RAILS

ABOUT LCC, LCA, RAMS AND CSR

As the leader in railway infrastructure technology, voestalpine has continuously strived to improve its products for all kinds of railway applications to reach the longest possible service lives and lowest maintenance needs, even under the most challenging conditions. The terms RAM (Reliability, Availability, Maintenance), LCC (Life Cycle Costs), LCA (Life Cycle Assessment) and in general CSR (Corporate Social Responsibility) have thus been key terms that have accompanied product development from the early days but have gained more and more importance over recent years.

The basis for any assessment of an innovation is its performance under operative conditions. At the same time, it is of the highest importance that the performance is described properly in various ways to support sustainable management decisions targeting technical, economic, ecological and social aspects. While LCC analyses evaluate all costs that arise during a product's life cycle, and thus reflect one of the most relevant criteria when purchasing new products, RAM reflects the technical basis for these analyses. In other words, RAM figures reflect the technical key performance indicators of railway components and only profound in-track evaluation with qualified personnel and sophisticated measuring equipment can form the basis for these evaluations.

Furthermore, taking its social and environmental responsibility very seriously, voestalpine is expanding the scope of assessment from the railway system to overall sustainable correlations. Life cycle assessment (LCA) is therefore used as a multi-step procedure for calculating the lifetime environmental impact of our products.

The overall global warming potential – "Carbon footprint" – of a railway infrastructure solution is ideally used to evaluate the environment impact of products. Thereby not only the production processes and technologies, such as the environmentally-friendly HSH® technology of voestalpine shall be taken into consideration. A representative economic and ecological product evaluation can only be made by focusing on a life cycle approach, considering all stages of a product's life in a holistic way ("from cradle to grave" principle).

Topics like procurement and transport of raw material, service life extension of products, reduced maintenance needs, optimized replacement, and recycling or reuse at the end of the life cycle are gaining more and more importance.

By significantly extending service lives and reducing maintenance requirements at the same time, the use of our HSH® rails not only leads to optimized LCC and RAM figures, but considerably affects the carbon footprint of rails in a very effective way.

With the aim of finding a customized rail investment strategy (placing the right rails in the right place) voestalpine has developed a range of different LCC-Tools which enable the customer to compare the economic and environmental impacts of different rail steels and various system solutions. Subsequently, the open-source methodology behind the tools will be described.

MODELING THE LIFE CYCLE OF A RAIL

Rails under operation underlie certain degradation mechanisms like wear, plastic deformation, RCF (Head Checks) and Corrugation (Figure 1).

To keep the rail in good condition and safe for operation, maintenance measures (grinding, milling, etc.) have to take place, when a certain operator defined threshold is reached. This requires the removal of material from the rail surface.

Usually, rail exchange is triggered when the total wear (natural wear plus artificial wear) reaches a defined rail renewal limit, mostly given by the operator. However, other criteria can also cause a rail exchange in track, such as the end of time of the superstructure (new-layer) or the fatigue limit of the rail. The latter being a practically theoretical limit since modern rails are intend to be "fatigue resistant".

The specific rate of each deterioration mechanism depends strongly on the respective track element (tight curve, medium curve, straight track, ...) and other boundary conditions. Thus, rail deterioration rate should ideally be deduced from long-term on-site measurements. However, if such data is not available e.g. in case of green field projects, generic data models based on global track measurements can be used for calculation.

Figure 1: Most common rail deterioration mechanisms

Figure 2 shows an examplary wear model for Metro Systems that is based on track experiences. It shows the dependency of wear on the curve radius of a Metro System.

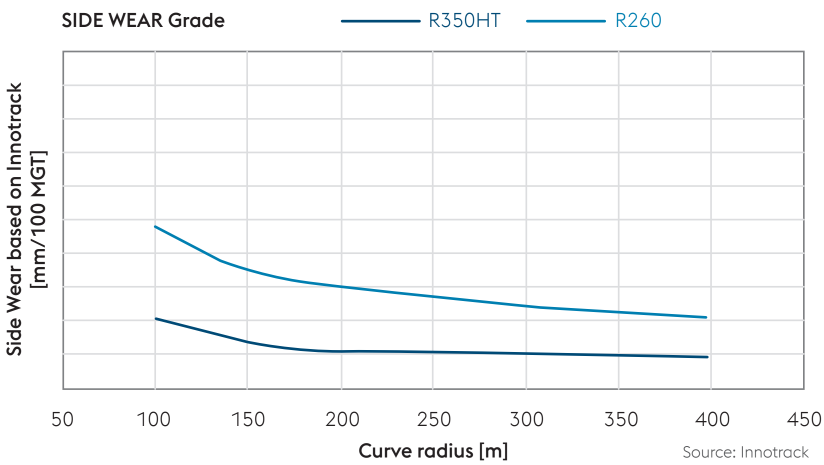
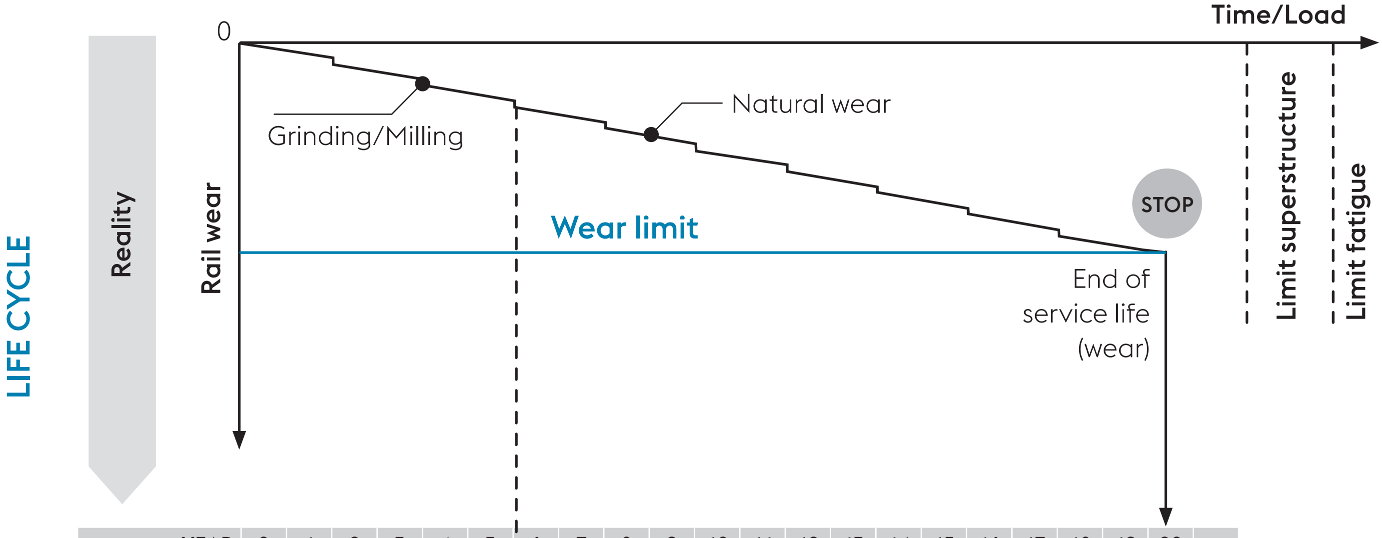


Figure 2: Example for a radius-based degradation model for wear based on track measurements

A combination of the different degradation models form the basis for modeling the Life Cycle. Generally these models can be created:

- With the knowledge of rail deterioration rates and specific operator based thresholds for respective maintenance measures
- or based on historic records of recent maintenance activities and experience of the usual life time of the rail in the respective track element

EXAMPLE FOR GIVEN RADIUS AND ANNUAL LOAD



YEAR	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	...
Rail exchange	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	...
Grinding	-	-	1	-	1	-	1	-	1	-	1	-	1	-	1	-	1	-	1	-	-	...

Figure 3: Schematic example for the life cycle of a rail in a curve with specific annual traffic load and radius

» From this time based description of the rail condition development, the amount of maintenance measures within the lifetime is deduced and can be assigned to a certain year in service to take into account dynamic interest effects (lower part of Figure 3).

RAIL – LIFE CYCLE OPTIMIZATION

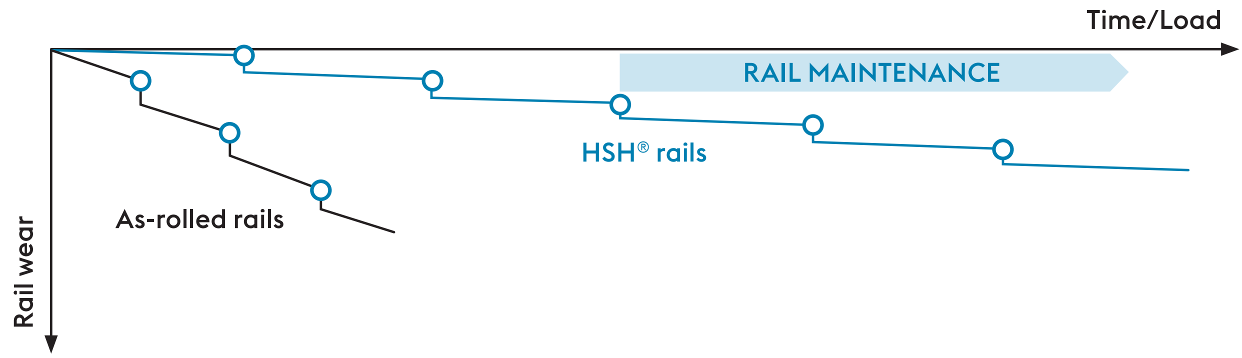


Figure 4: Schematic illustration – Influence of the rail steel on the Life Cycle of a rail in a curve

Although generic rail deterioration data might not match perfectly each particular situation (real track behavior), it is reliable enough for an investment strategy on a principal level. The factor of improvement between different rail steels has proven to be constant under given (constant) circumstances. This mainly depends on the increased material resistance against wear, Head Checks, Corrugation and the correlating profile stability (Figure 4).

If local measurement data is available for several track sections, this data can be used to calibrate the models and reach a better fit with real operational track behavior. In best case, measurement based degradation data for single track elements (curve, tangent) is used for the calculations.

KEY PERFORMANCE INDICATORS OF LCC AND RAM ANALYSES

The long service lives of rails demand the use of dynamic investment appraisals which incorporate interest rates to include costs for capital commitment and inflation. Thus subsequent methods are usually used to determine if a product is economically beneficial:

LCC-KPIs

Net present value

- The net present value reflects the sum of all costs arising in a defined time span (usually 30 to 40 years) including costs for rail renewals and maintenance, as well as operational hindrance costs
- In case life spans of certain rail steels exceed the defined period under consideration, a residual value needs to be recognized

Equivalent Annual Costs

- This method allows a direct comparison of the average annual costs of different strategies
- For easier understanding it can be compared to the rate of a loan that would be raised at the beginning of the period

Time / Payback time amortization

- Determines the pay-back-time of the differential investment costs
- Is calculated as the intercept point of cash-flow-curves

Internal rate of return

- Describes the hypothetical rate of interest by investing in a better performing product
- It takes into account the differential investment costs and the savings due to better performance

RAM-KPIs

Rail service life (MTBR)

- Is the expected service life of a rail for the given track element in MBGT

Maintenance interval (MTBM)

- Is the expected grinding or milling interval of a rail for the given track element in MBGT

Maintenance duration

- Is the time the track element is not available for service due to construction or maintenance works [hrs or hrs/y]

Technical non-availability

- Reflects percentage of hours of non-availability out of the total operating time of a system

INTERPRETATION OF THE LIFE CYCLE ASSESSMENT

Life Cycle Assessment (LCA) is an important methodological tool used to assess the potential impact of products on the environment, throughout its entire life cycle. In order to allow a reliable prediction of the ecological advantages of a product and prevent shifts between the different phases of life, all stages from raw material procurement to end of service life shall be taken into consideration. Environmental product declarations (EPDs) are independently verified and registered documents, which communicate transparent and comparable information about the life-cycle environmental impact of products. EPDs evaluate various parameters on the environmental impact of products, taking into account the entire life cycle of a product.

Our third party verified EPD for voestalpine rails is based on life cycle assessment data and delivers input data for the global warming potential (GWP) of rail products during the entire life cycle. The EPD is calculated based on the European standard EN15804 and the international standard ISO14025, verified by the internationally recognized institute “IBU” (Institut für Bau und Umwelt).

Environmental emissions generated during the production stage shall be qualified by the actual service life, especially the extended service life due to high product quality and optimally selected application area leads to a distinctly reduced GWP per year. Thus, life cycle optimization means utilizing correctly applied premium products and services leading to significant reduction of environmental impact and corresponding carbon footprint. Therefore, the developed LCC-tool focuses on the GWP (CO_2-equivalent) of the production stage, including raw material supply, transport and manufacturing processes (refer to stage A1-A3 in the EPD).

Based on the necessary amount of rail replacements an accurate value for the environmental impact of different rail grade strategies can be evaluated. The calculation does not take into account various environmental effects caused by the transport and installation of the rails, due to the negligible effect on the GWP, resulting in a conservative estimation of the potential for savings due to extended service life of a product.

IMPROVING LCC AND GLOBAL WARMING POTENTIAL BY USING SUPER PREMIUM RAIL STEELS

SINGLE CURVE (MIXED TRAFFIC)

The economic and ecological savings potential is displayed best, when comparing different rail steels in track. A R=350 m curve in the Viennese Undergound Line U6, where the operational performance of different rail steels has been monitored since 2015, serves as an example for how to assess the benefits of more resistant rail steels. In the curve 400UHC® rail on high- and low-rail have been compared to the Viennese rail grade standard of that time using R260 rail steel for low rails and R350HT rail steel for the high rails.

Already after 2 years which corresponds to approximately 37 MGT, the 45° side wear (W3) of 400UHC® rails showed approximately 50 % reduced rail wear. (Figure 5)

Radius: 350 m
Total Load: after 37 MBGT
Customer: Wiener Linien

Alternating implementation of different rail steels displays the wear behaviour of 400UHC® HSH®#

Average R350HT ... 1.5 mm

Average 400UHC® ... 0.7 mm

Factor of improvement ~ 2

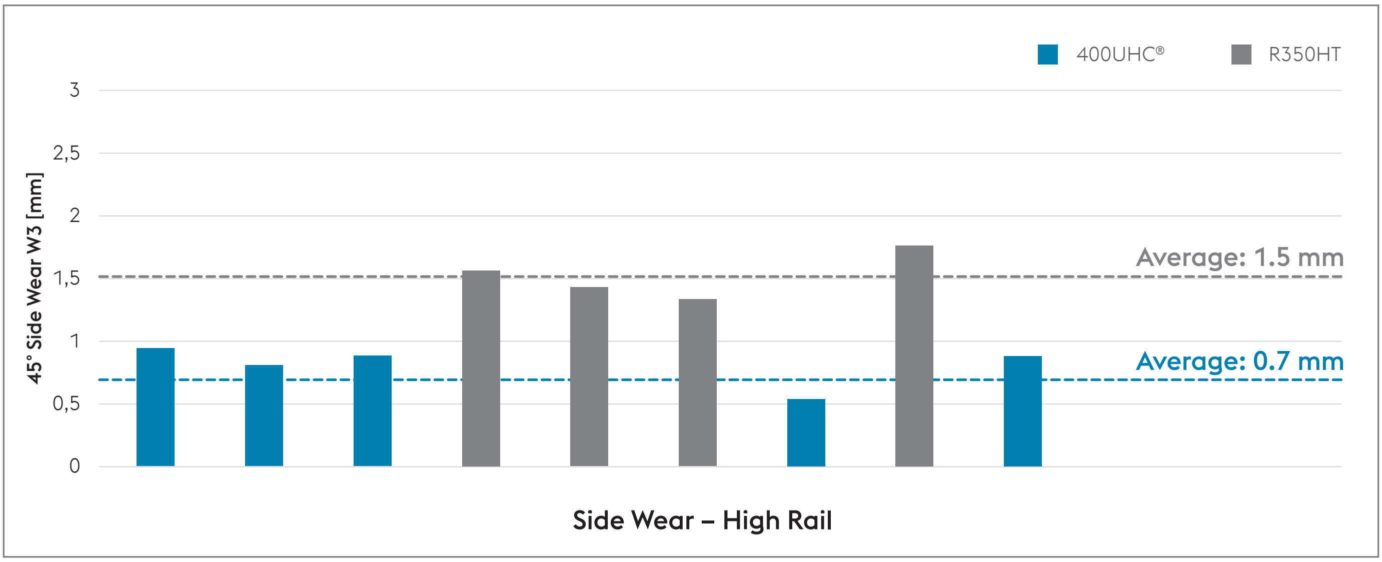


Figure 5: Rail Wear – longest possible service life

Further improvements have been observed regarding the resistance against corrugation and Head checking (Figure 6 and 7). While corrugation was already at a significant level after 37 MBGT (0.2 mm), 400UHC® rails didn't show corrugation at all.

Radius: 350 m
Total Load: after 37 MBGT
Customer: Wiener Linien

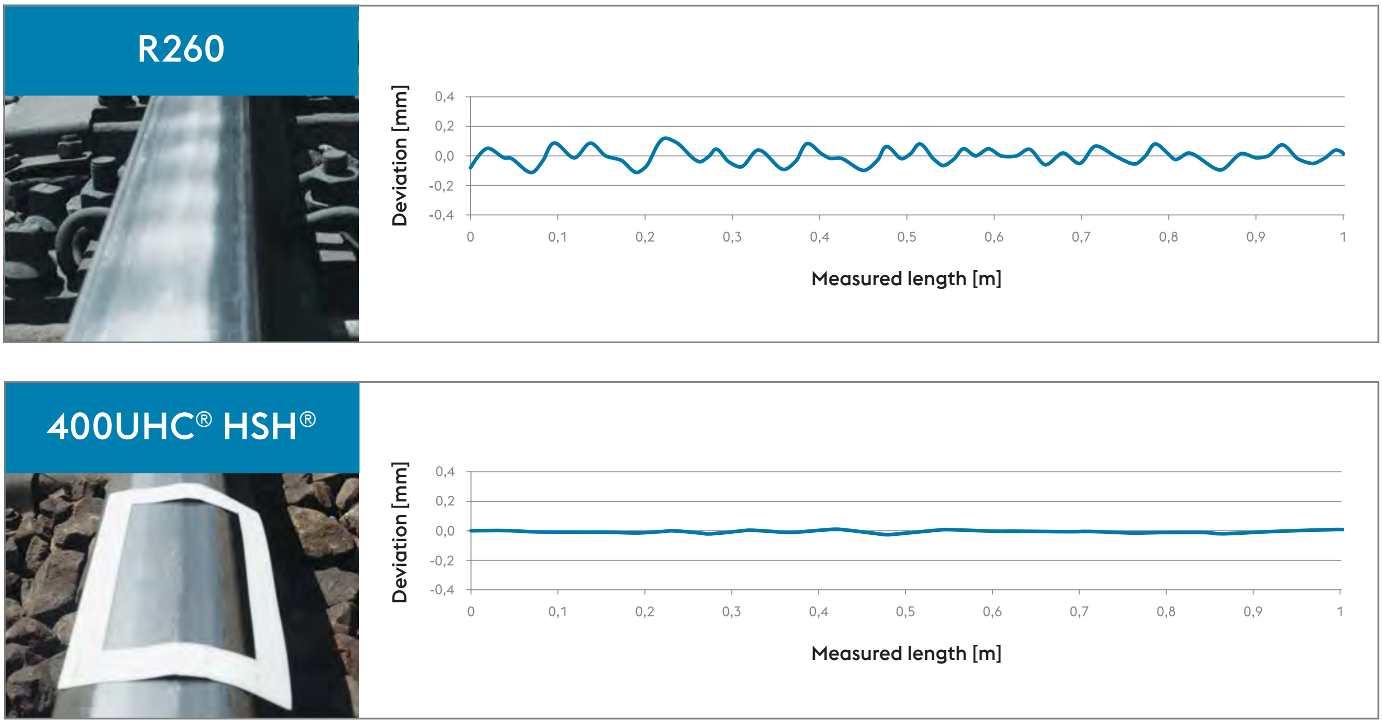


Figure 6+7: Longitudinal profile measurement after 37 MBGT

An Eddy Current measurement to assess the Head Check depth at the high rail was performed after the same total load, indicating a 50 % reduction of the RCF depth from approximately 0.7 mm to approximately 0.35 mm. (Fig. 8)

Radius: 350 m
Total Load: after 37 MBGT
Customer: Wiener Linien

Results Eddy Current:

400UHC® HSH® – 50 % RCF reduction

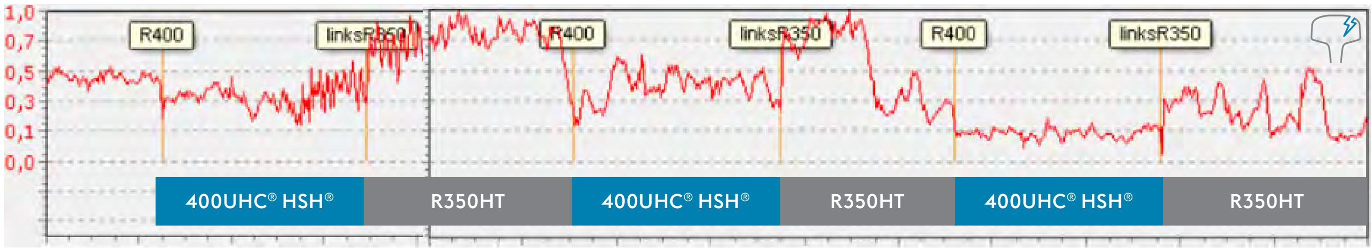


Figure 8: The eddy current testing (by external company) allows a qualtitative evalutation of Head Check depth:

LIFE CYCLE MODELLING, LCC AND CO_2-EQUIVALENTS

Considering the measurement data of the 400 UHC® HSH® rail steel (R400HT) and the the current strategy R260/R350HT, a significant stretch of grinding/milling intervall and rail service life is the consequence .

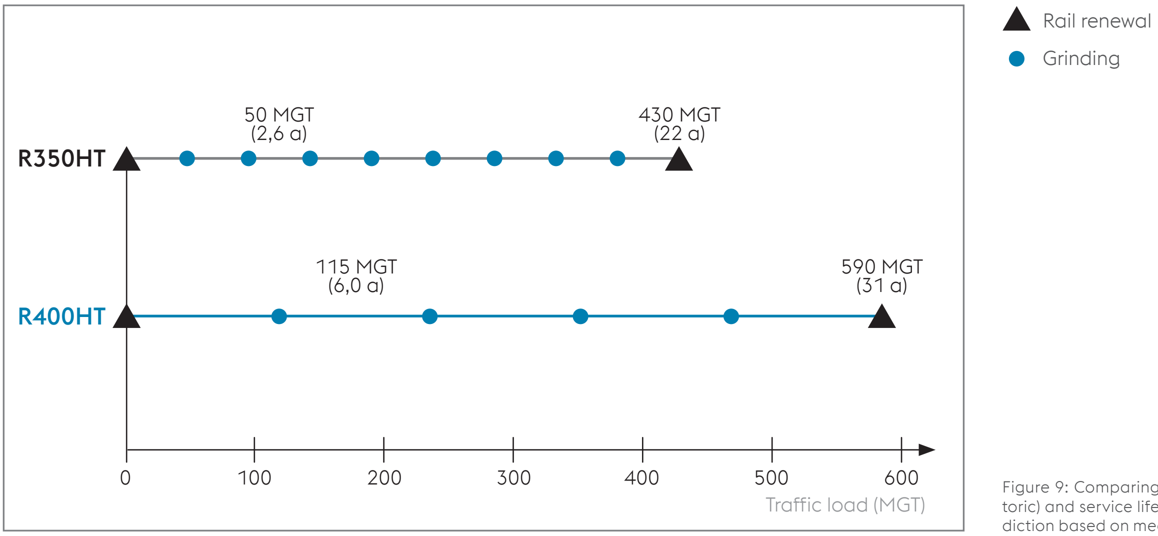


Figure 9: Comparing service life of R260 (historic) and service life of 400 UHC® HSH® (prediction based on measurements)

While the Life Cycles speak for themselves, the cost benefit is also significant. A **reduction of equivalent annual costs of nearly 30 %** is a consequence of the superficial operational behaviour.

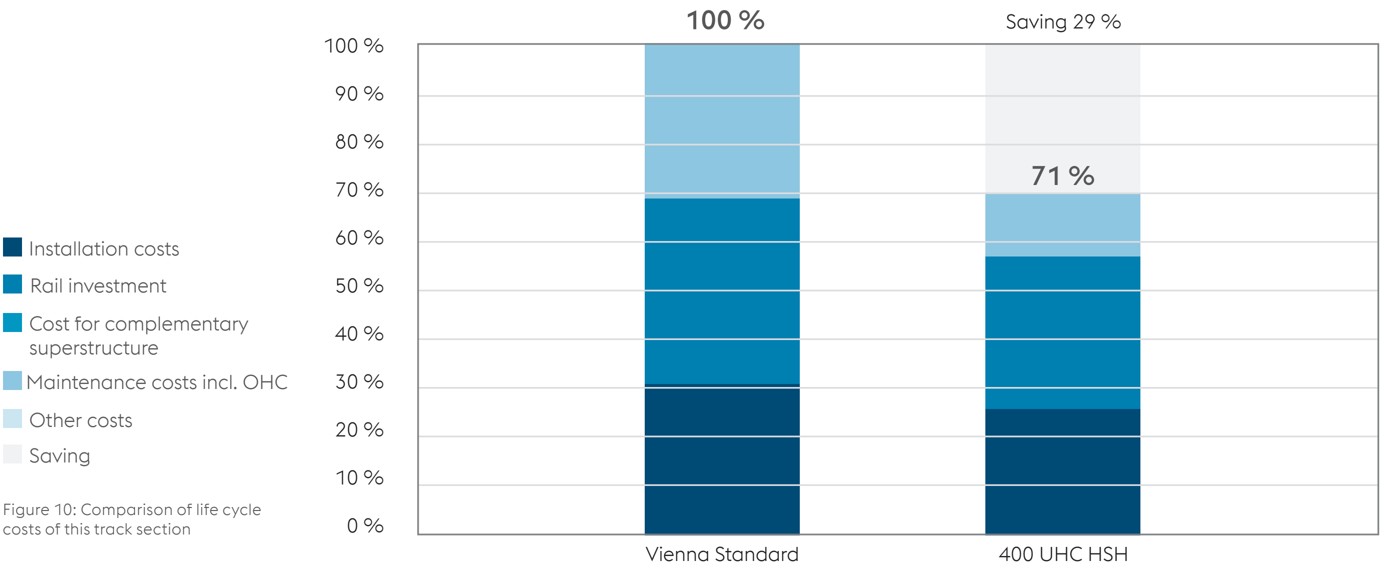


Figure 10: Comparison of life cycle costs of this track section

Considering the service lives and corresponding re-railing rates, the **average annual global warming potential (CO_2 equivalent) per km track can be reduced by 29 %** by using R400HT instead of R260.

ANALYSIS FOR A METRO SYSTEM

Using above methodology in voestalpine LCC-rail tool, metro tracks can be analysed on the basis of Open Street Map Data or other sources of track geometry data. The AUSTRIAN “U4” railway corridor serves as an example for a track-wide analysis of the environmental impact when using an “innovative rail grade strategy” (400 UHC® HSH®) in curves R < 1.500 m and R260 for wide curves and tangents) compared to widely used “standard-strategy” of using R350HT in cruves R < 1500 m and R260 for wider curves and tangents. The calculation is based on generic degradation models for Metro Systems.

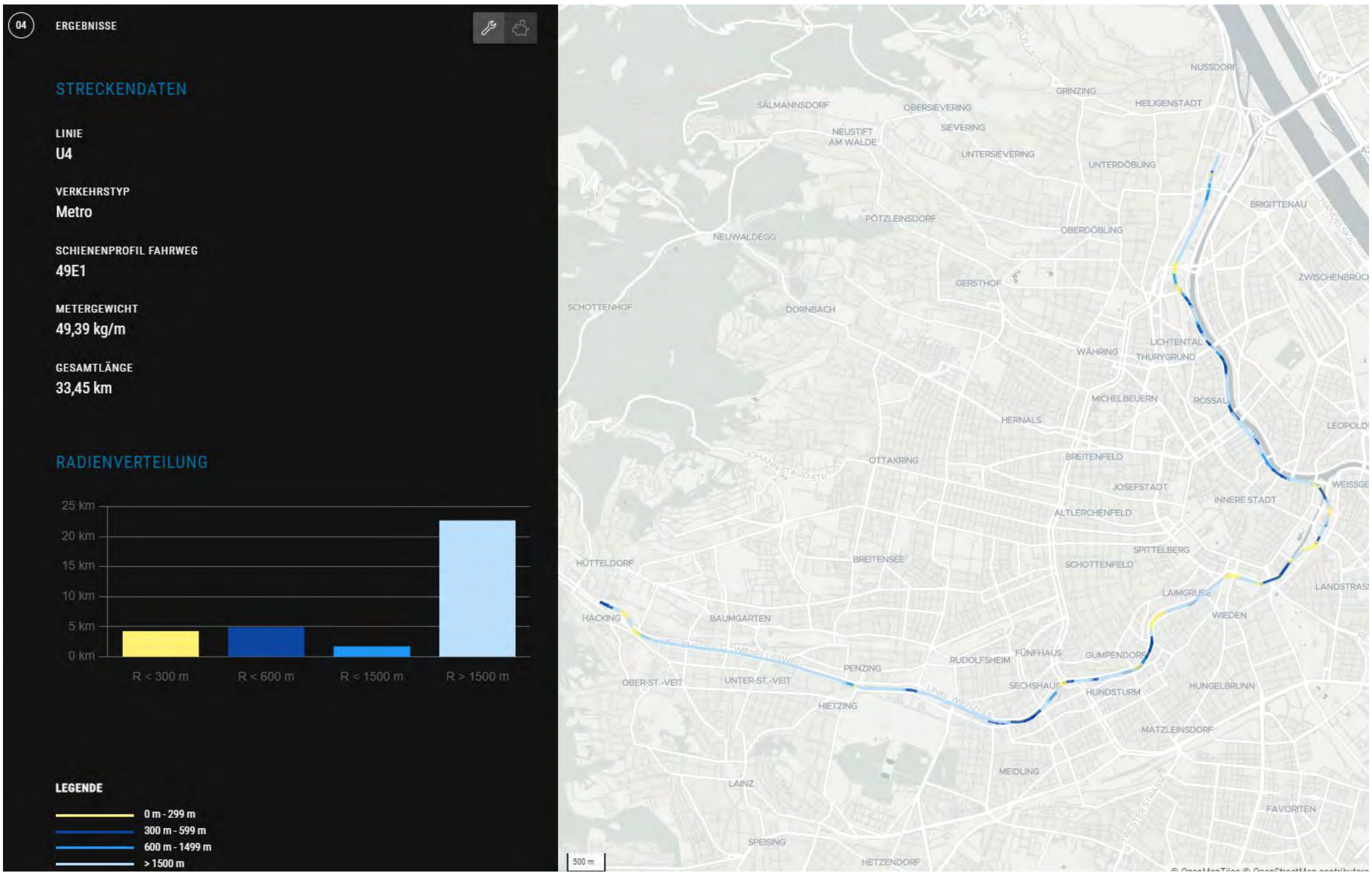


Figure 11: Overview and radii distribution – Rhine-Alpine-corridor

An analysis of the **equivalent annual costs** demonstrates the impact on rail related Life Cycle Costs by using the rail steel 400 UHC® HSH® in curves below 1.500 m instead of R350HT:

COST REDUCTION	
Base strategy **Strategy “R350HT in curves”**	Reference
Innovative rail steels **Strategy “400 UHC® HSH®” in curves**	87 %

The **estimated global warming potential** for the different rail grade strategies is as follows:

CO_2 EMISSION REDUCTION	
Base strategy **Strategy “R350HT in curves”**	Reference
Innovative rail steels **Strategy “400 UHC® HSH®” in curves**	87 %

YOUR INDIVIDUAL ANALYSIS

Above examples demonstrate the impact of rail steel grade strategy on costs and sustainability, showing that a degradation-based choice of rail steel can significantly contribute to the reduction of Life Cycle Costs and the global warming potential through longer rail service life and reduced maintenance. By using our software tools, we can assist you with tailor-made LCC-analyses.

Contact us to determine an optimized rail grade strategy for the highest economical and ecological savings for your project:

product_management@voestalpine.com

You can expect:

» **LCC analysis**

- Net present value
- Equivlent annual costs
- Payback-time amortization
- Return on invest
- Rate of return

» **LCA analysis**

- Equivalent annual CO_2 emissions

» **RAM analysis**

- Expected rail service lives (MTBR)
- Expected maintenance cycle (MTBM)
- Expected total maintenance duration
- Expected technical non-availability

Analyses can be conducted for all modes of railway application:

» Mixed Traffic and High Speed
» Heavy Haul
» Metro
» Tramways

ANNEX

REQUIRED INPUT DATA for your individual LCC analysis

For an individual LCC analysis, best results are achieved when respective data is provided.

Financial data

Corporate cost of capital [%]	
Inflation [%]	
Currency	

Note that the world-bank suggests costs of capital at around 4 %.

Track and degradation data:

LCC analyses can be done for single or multiple curves as well as for whole railway lines – please fill in representative data for the respective option:

Option 1: Single or multiple curves based on measurement data					
Curve radius [m]	**Segment length** [m]*	**Current rail steel**	**Natural rail wear of current rail steel** [mm/100MGT]	**RCF-development of current rail steel** [mm/100MGT]	**Development of corrugation of current rail steel** [mm/100MGT]

Please also provide:

- » Limit of service life due to fatigue of rails [MGT]
- » Service life of residual superstructure – defining the track new-layer [MGT]

Option 2: Single or multiple curves based on maintenance experience				
Curve radius [m]	Segment length [m]*	Current rail steel	Service life [MGT]	Maintenance interval [MGT]

Option 3: LCC for railway lines

Subsequent sources can be used to import track data:

- Openstreetmap: Can be used, if track is recorded in openstreetmap.org in good quality. Note that the data is interpreted by a computer algorithm. Thus, slight deviations from real track geometry might appear. Map-Visualization of the results is possible.
- CSV-files: Importing track geometry information in form of CSV-files allows a precise analysis of track geometry and shall include subsequent information. Note that a map-visualization of the LCC-results is not possible when using CSV-track-data.
  - Curve radius [m]
  - Segment length [m]
- DXF-files: A dxf-drawing of a railway-line can be imported. Please note that the plan will only include the lines without any other information, except the geo-coordinates of two different reference points.
- Clustered track information: Track elements that are clustered in groups of radii and their corresponding sum of lengths can be used as basis for a quick LCC-estimation. Please note that clustering of elements leads to reduced precision.

Calculation can be conducted by using voestalpine's generic degradation models. However, the use of degradation models based on on-site measurements will increase the precision of the LCC-analyses. Please provide subsequent data in this case.

Curve radius [m]	Current rail steel	Natural rail wear of current rail steel [mm/100MGT]	RCF-development of current rail steel [mm/100MGT]	Development of corrugation of current rail steel [mm/100MGT]

Please also provide:

- Limit of service life due to fatigue of rails [MGT]
- Service life of residual superstructure – defining the track new-layer [MGT]

Traffic data

- Annual load [MGT]

Maintenance Data

- Average time for rail exchange: hrs/km

- Type of maintenance: Grinding/Milling
- Average time for rail maintenance action: hrs/km
- Metal removal rate for RCF
- Metal removal rate for corrugation

- Wear limit [mm]

- Limit for RCF and corrugation, in case no maintenance is conducted [mm]

Costs

- Average transport costs of rails to construction site [Currency/to]
- Additional costs for rail exchange [Currency/m Track]
- Costs for rail maintenance [Currency/m Track]
- Operational hindrance costs (when available) for rail renewal and rail grinding

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