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Best practices of track maintenance for a High performance railway track

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October 2015

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This presentation has been delivered at a Workshop at the "Rail Engineering & Maintenance Summit" on 27/10/2015 in Singapore

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- Civil Engineer (MSc.) - University of Hannover in Germany
- Master Executive MBA degree - Athens University of Economics & Business
- Over 30 years of experience in the railway sector, including eight years in Director positions at Greek Railways Organization (OSE S.A.)
- 2013, 2014 development of the Omani National Railway Network
- 2015-today: Senior Railway Expert at the Ministry of Transport and Communications in Oman
- Website **www.railhow.com**, aiming to be the touchstone for people who are working within the engineering sector by offering practical, yet impactful knowledge and learning experiences.

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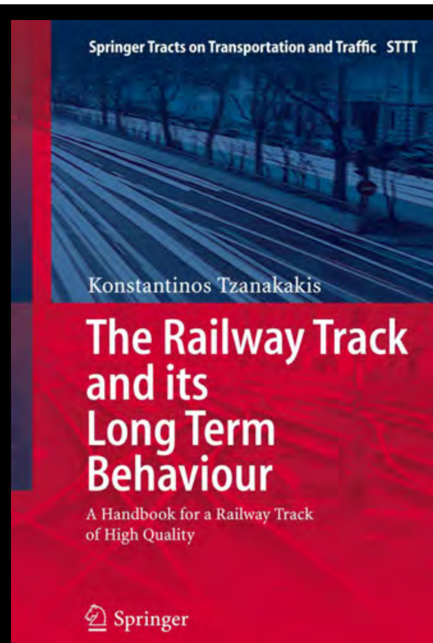
- The presentation is based on the book



Basic Source: Prof. Peter Veit, Technical University of Graz, Austria

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Workshop Structure

PART 1: THE ACTING ENVIRONMENT FOR THE IM

- TECHNOLOGICAL DEVELOPMENTS AND TENDENCIES FOR THE RAILWAYS
- THE EXTERNAL ENVIRONMENT OF THE IM

PART 2: QUALITY OF AND FOR THE TRACK

- THE RAILWAY TRACK AS A SYSTEM
- THE TRACK DEGRADATION (The deterioration of the track components, Subgrade degradation, Track drainage
- TRACK QUALITY (Quality and safety, The importance of high initial quality, Mathematical models for predicting the track quality, Parameters affecting the track quality over time)

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PART 3: TRACK MAINTENANCE

- INTRODUCTION TO TRACK MAINTENANCE (The maintenance objectives, Track condition monitoring, Types of maintenance)
- THE VARIOUS MAINTENANCE STRATEGIES AND THEIR IMPACT ON THE SERVICE LIFE OF THE TRACK
- THE RATIONAL MAINTENANCE (The “old maintenance strategy” concept, the “future” maintenance strategy)
- TOOLS FOR PLANNING A RATIONAL MAINTENANCE (RAMS, LCC Analysis: Which is the best way to maintain the track? How can it be ensured that over time the current maintenance practice is the most effective one?)
- GUIDING PRINCIPLES FOR AN EFFECTIVE TRACK
- INNOVATIVE SOLUTIONS TO REDUCE MAINTENANCE NEEDS
- INVESTMENT AND BUDGETING DECISIONS
- CONCLUSIONS FOR EFFECTIVE TRACK MAINTENANCE

PART 4: TRACK QUALITY – BAD EXAMPLES (Learn from our mistakes)

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PART 1: THE ACTING ENVIRONMENT FOR THE INFRASTRUCTURE MANAGER (IM)

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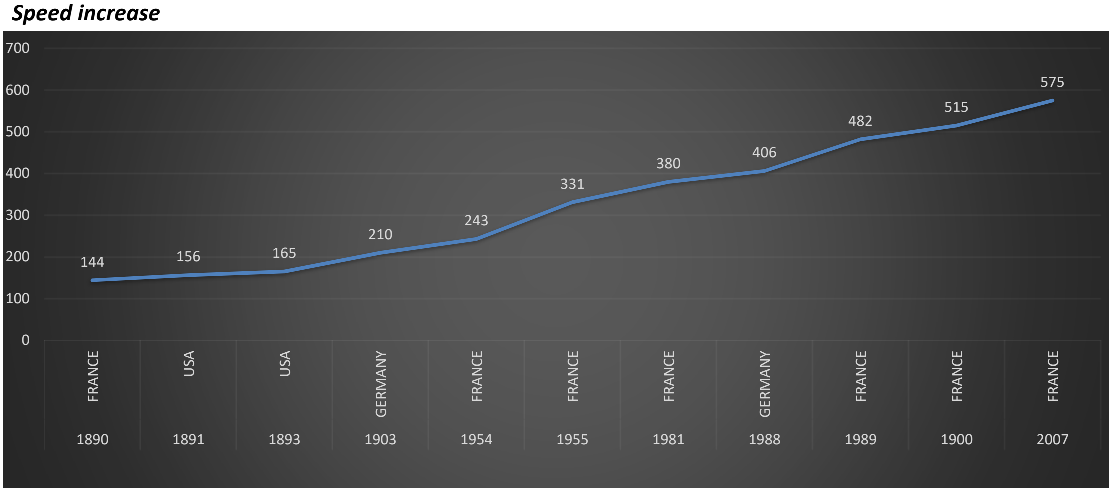
Some technological developments

Speed increase



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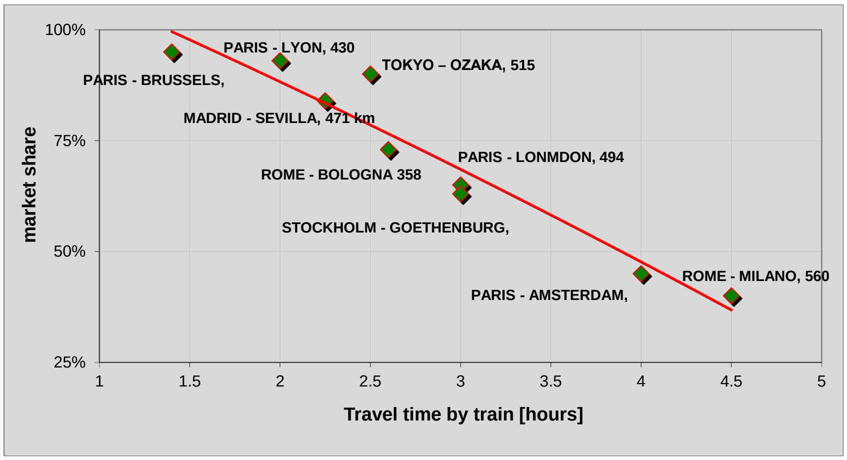
Relation between travel time and market share



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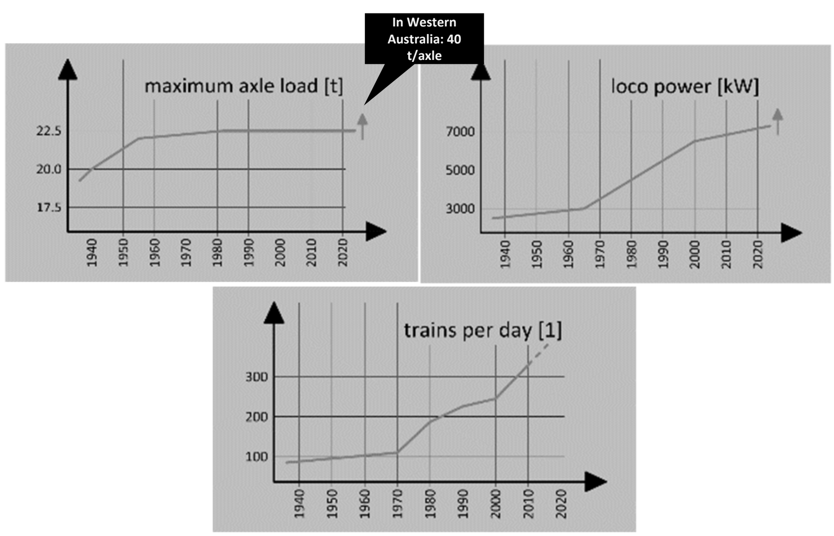
Tendencies for the railways



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Australia: Fortescue Metals Group Ltd private railway with 40t axle load

- Fortescue Metals Group Ltd is an Australian iron ore company. Fortescue is the fourth largest Iron ore producer in the world as of March 2011.
- The company has built a mine, a 260-kilometre (162 mi) private railway and a new port at Point Anderson.
- The "first ore on ship" on the line occurred in May 2008, 3.5 years after construction started.
- The 1,435 mm (standard gauge) heavy haul railway is used by 35,200-tonne trains up to 2.5 kilometres long at 40-tonne axle load.

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The external environment of the IM

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The new requirements to the IM

Reduce of funding

Cost reduction

Review of
Current practices, finding ways of better functioning, set up new strategies

Target: performance improvement of the railway system

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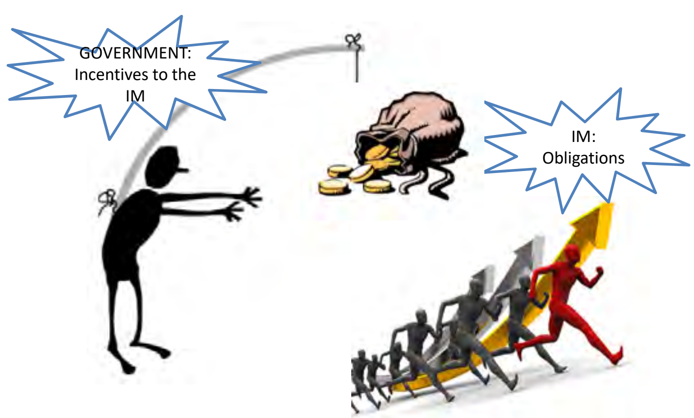
Multiannual contracts (IM – Government)



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Challenges for the IM

The Infrastructure Manager faces the following challenges, to be fulfilled all at the same time:

- Ensure the **safe operation** of the railway infrastructure
- **Decrease his costs** for the maintenance of the railway infrastructure and the traffic management
- **Increase the efficiency of the railway infrastructure**.

- The Infrastructure Manager has to optimize his way of operation. The only way to achieve this target for the maintenance of railway infrastructure is included in the word "**Quality**".
- If the Infrastructure Manager can achieve to get a new track of high quality, to maintain it with the optimum maintenance strategies, he will be able to manage a track with low costs and a high efficiency.

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PART 2: QUALITY OF AND FOR THE TRACK

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The railway track as a system

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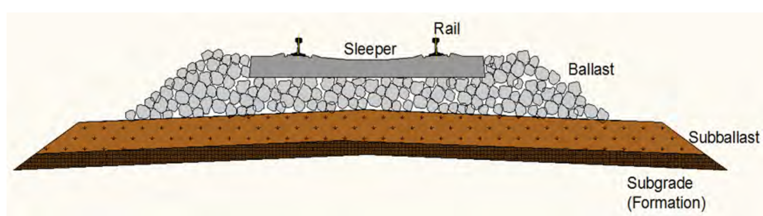
The track components

Track components are grouped into two main categories:

1. the superstructure
   - rails,
   - sleepers
   - a fastening system to hold the components together
   - ballast

2. the substructure
   - sub-ballast and the
   - subgrade or formation.



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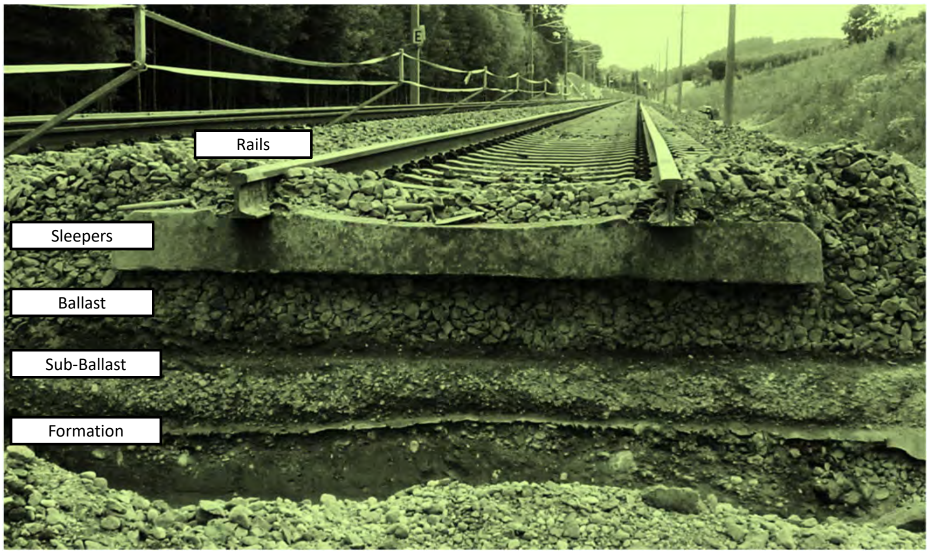

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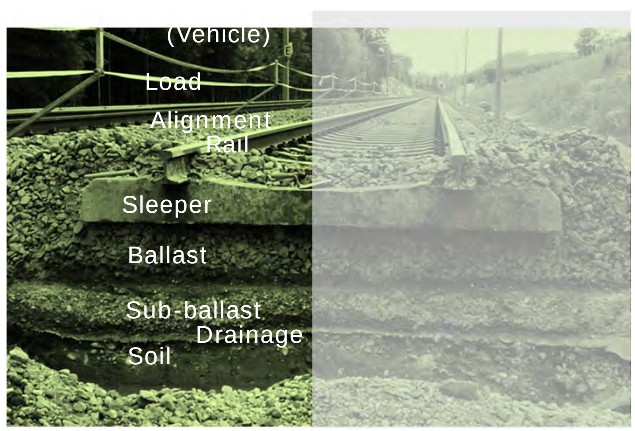
The track superstructure as a "system"

The track is a complex engineering structure.
The track is not a random composition of various elements

→ The track should be considered as a whole, not the individual elements separate.



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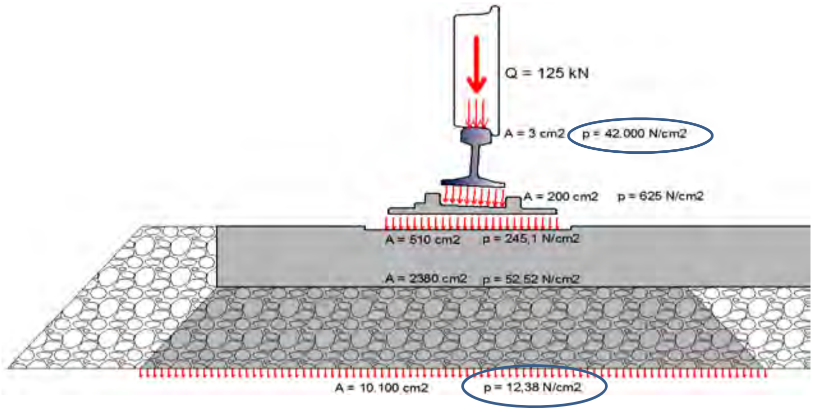
Carrying the loads of the trains



Pressure distribution of the wheel force Q in the individual system components of the track

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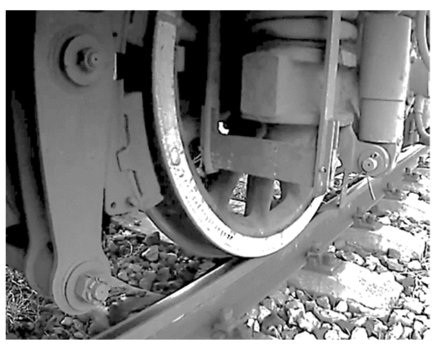
The wheel / rail interface

- The wheel/rail contact determines the capabilities of the railway system.
- This contact is the critical point at high speeds and in cases of heavy freight trains with high axle load, due to the high contact forces and the dynamics, but it is also responsible for noise emissions and wear.

VIDEO



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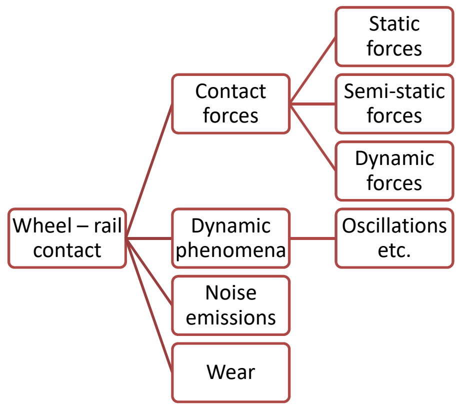
Wheel-rail contact impacts



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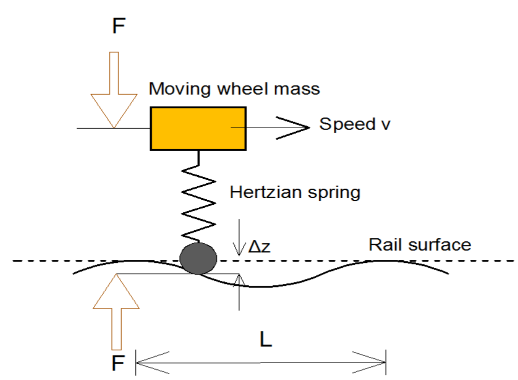
Train running on the track

- Vehicle and track can be seen as oscillatory systems. When a train is running, there are dynamic interactions between the two systems.
- Dynamic effects in the complex train – track system become more significant when train speed increases and when the axle load gets higher.



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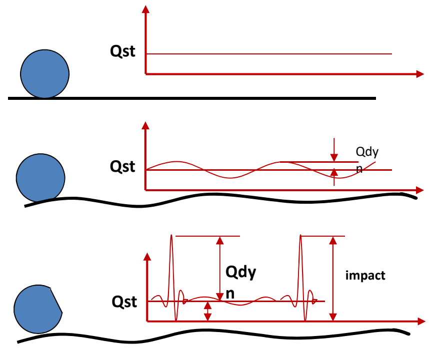
Wheel and track in a perfect condition

Track with irregularities

Track and Wheel with irregularities



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- The following example demonstrates the impact of a track fault (a faulty weld on the rail) with changes in the individual system characteristics that lead to changes of the dynamic loads.

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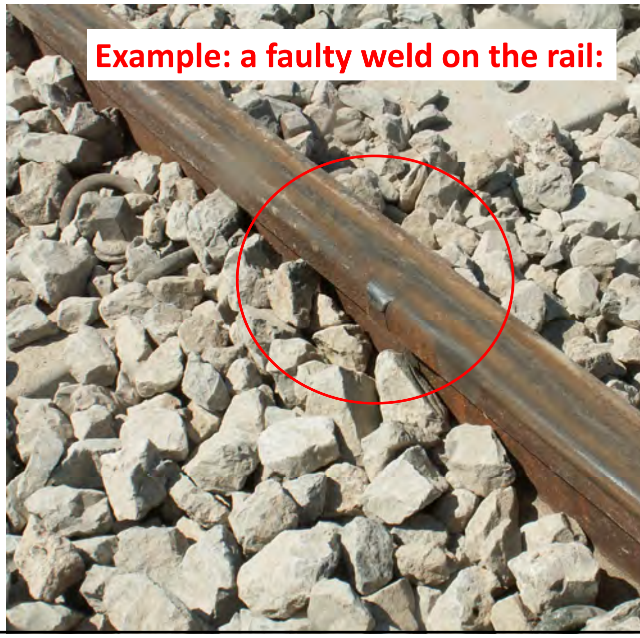

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Example: a faulty weld on the rail:

Cause	Impact	Explanation
Faulty weld on the rail	*Forces at a running train*	*A faulty weld on the rail, induces forces at a running train*
	Wear on individual ballast stones	*The forces are transmitted through the sleepers to the ballast.* *In the ballast bed, as a result of the big forces, an increased wear on individual ballast stones arise*
	Track settlements	*The position of the stones with each other changes, which results in track settlements.*
	New interactions between the vehicle and the track	*Caused by the changed track position and changed ballast properties there are new interactions between the vehicle and the track*

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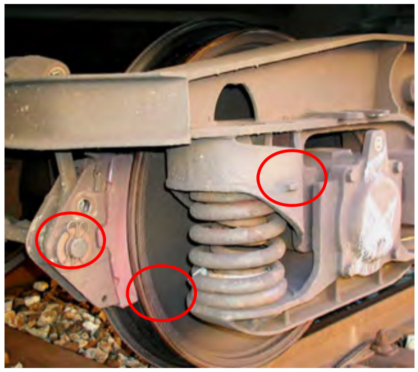
Boogie wear / damage due to wheel irregularities

Wheel irregularities



Consequences on the boogie

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Wheel irregularities affect the rails and vice versa

Track irregularities affect the wheels and wheel irregularities affect track quality.

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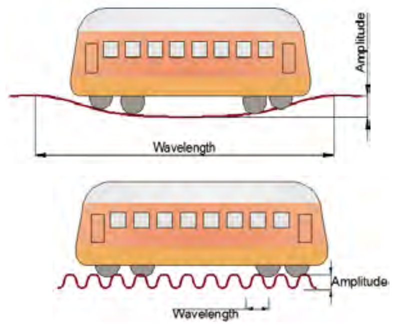
Irregularities and impact loads generating excitation frequencies

The sources generating train and track vibrations are:

- long wavelength irregularities and
- short wavelength irregularities (railhead corrugation),
- impact loads.

Long wave track irregularities tends to cause body vibration, affecting the riding comfort

Short wave length track irregularity tends to cause wheel vibration, affecting axle weight fluctuation and vibration



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Corrugation - Short wave length track irregularity

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Conclusion

- As speed increases, the greater the need for high quality and small faults
- As the requirements for high comfort increase, the greater the need for residual faults have a large wavelength

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The track degradation

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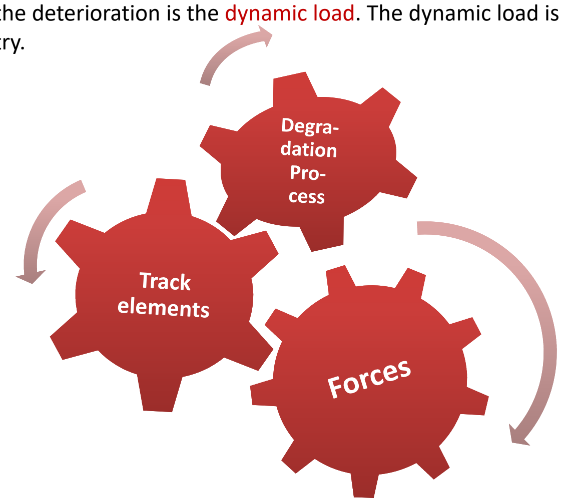
Deterioration processes in brief

- Deterioration or degradation is the *reduction of the original quality due to various influences*.
- By far the most significant factor contributing to the deterioration is the dynamic load. The dynamic load is directly related to the axle load and track geometry.
- The main processes of track deterioration are
  - wear,
  - fatigue and
  - settlement.



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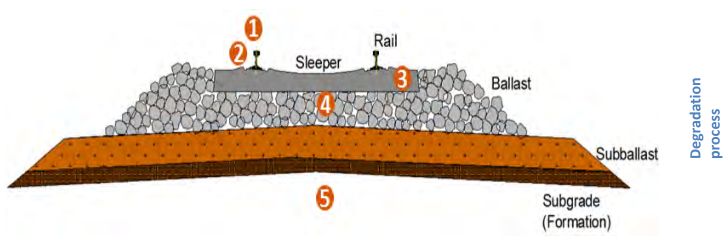
The mechanism of the track faults creation

The mechanism of the track faults creation can be presented briefly and simplified as follows:

- Track irregularities (track geometry or running surface) ❶ lead to increase of the dynamic forces, which accelerates the rail wear. Through the fasteners ❷, the consequences are transferred to the sleepers ❸ and the ballast ❹ and finally to the substructure ❺.

- As a consequence, fine material from the substructure goes up to the ballast.
- The existence or entrance of water to the ballast bed accelerates the deterioration procedure of the track.



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Factors influencing the railways infrastructure deterioration

Three main groups of factors may be distinguished that contribute to the deterioration of railway infrastructure:

- **Use**: wear by physical contact, static and dynamic load
- **Environment**: climatic influence, water
- **Failures**: faulty components, bad construction

In most of the cases it is not just one of these factors that causes deterioration, but a combination of them.

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THE DETERIORATION OF THE TRACK COMPONENTS

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The Ballast

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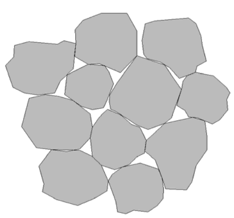
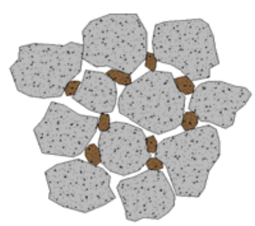
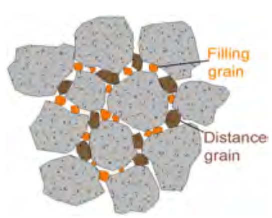


Clean new ballast (skeletal grains)



Ballast after operating loads (skeletal and distance grains)



Dirty ballast

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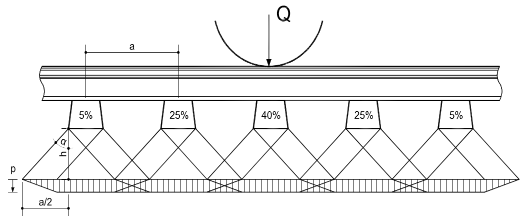
Ballast thickness dimensioning



$$\tan\alpha = \frac{\alpha/2}{h} \rightarrow h = \frac{\alpha}{2 \cdot tan\alpha}$$

Angle of friction α			
42º	39º	30º	20º
Ballast thickness [cm]			
33	37	52	82

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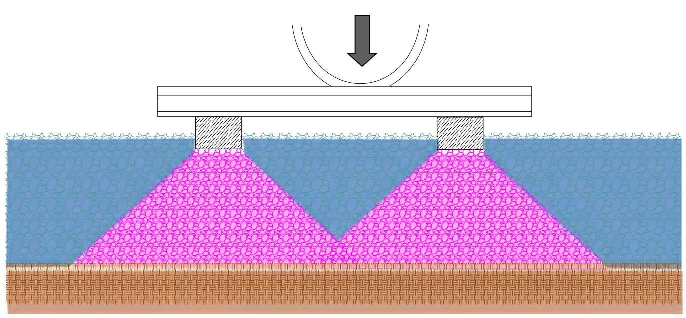
Case 1: Perfect ballast quality, right thickness

- The friction angle of new, good quality ballast is ≈ 42º
- Due to some wear during transport and distribution on the track bed, the friction angle is taken to 39º
- Good quality and right ballast thickness → uniform stress distribution on the soil



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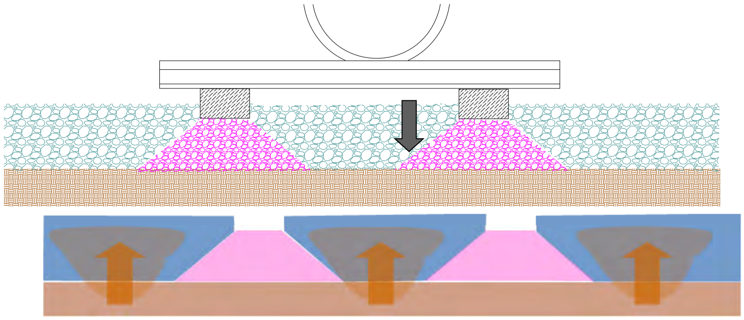
Case 2η: Perfect ballast quality, insufficient ballast thickness

- Due to the insufficient ballast thickness the load of the train operation is not transferred uniformly to the soil.
- The “load cones" are pushing to the ground and soil material penetrates to the ballast layer. Result: the **ballast is contaminated**



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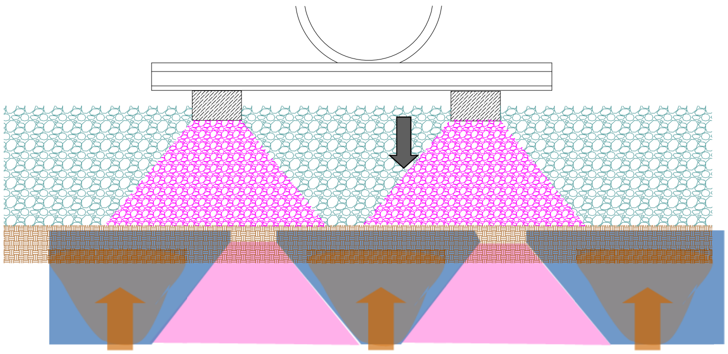
Case 3: Bad ballast quality, right thickness

- The angle of friction of the contaminated ballast is decreased up to 20º
- The “load cones" are pushing to the ground and soil material penetrates to the ballast layer. Result: the **ballast is contaminated**



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Dirty ballast at ballast depot

Unsuitable ballast in track

Vegetation in a track
with unsuitable ballast

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Effect of irregularities and inhomogeneity in the track: Pollution of the ballast bed

- Pollution of the ballast bed, implies an **unfavorable pressure (stress) distribution in substructure**.
- The pollution caused by **rising of fine material from the soil** is accelerated.
- The **longitudinal track profile starts to get errors**. Restoring the profile has only short term results.
- The **track condition deteriorates rapidly** which can sometimes lead to derailments.

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The Rails

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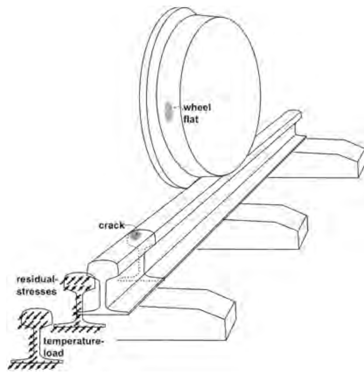
Rail breaks

- Stress that can lead to rail breaks:
  - –Stresses caused by wheels with flats (Bending stress)
  - –Stresses due to thermal stresses
  - –residual stresses



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Hatfield derailment (UK)

Broken Rail in Greece (Kilkis Area, 2008)

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Rail deterioration

Wear

Rolling Contact Fatigue

Factors which affect the service life of the rail:

- **Wear**: lateral and vertical
- **Rolling Contact Fatigue**: Headhecks, Spalling, Squats, Belgrospies
- **Plastic deformation**
- **Grinding** (frequency, metal removal)

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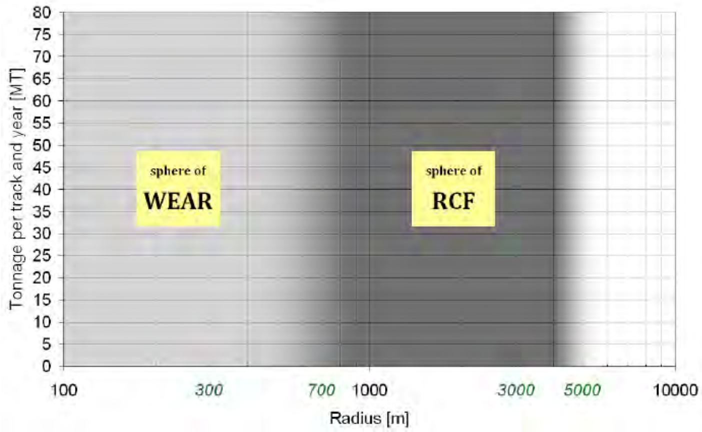
The wear of the rails in relation to the radius



Source: INNOTRACK – D4.1.5

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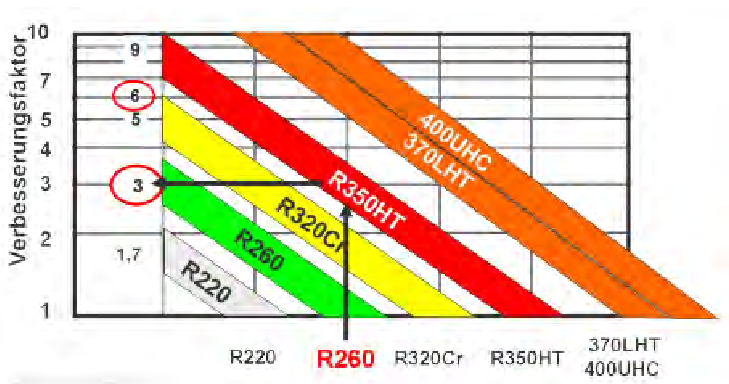
Improving the wear of rails depending on the selection of quality rail



LCC der Gleiskomponenten, Dipl.Ing. Dr. Peter Pointner

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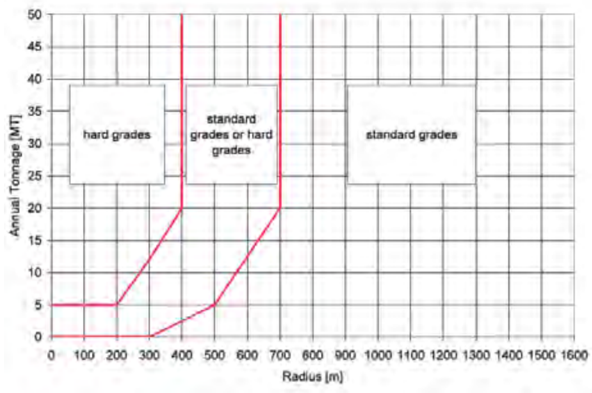
Selection of the appropriate steel grade (1)



According the UIC Leaflet 721

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Selection of the appropriate steel grade(2)

Radius [m]	≤ 300	400	500	600	700	800	1200	1500	2500	≤ 3000	> 3000
UIC	R350HT		R350HT/R260			R260					
Germany	R350HT (≥ 30 MGT)					R260					
Germany - New Track	R350HT (≥ 50 MGT)								R260		
Switzerland	R350HT		R320Cr/R350LHT				R260				
Switzerland (Trial)	370LHT		R350LHT		Bainitic			R260			
Austria	R350HT	R260									
Austria (New) Single Track	R350HT	R260									
Austria (New) Double Track	R350HT										R260
Sweden	R350HT	R260									
Sweden (Malmbanan)	R350HT										R260
Norway	R350HT					R260					
UK	R260										
Ireland	R260										
Italy	R260										
Belgium	R350HT					R260					
Luxembourg	R350HT					R260					
Netherlands	R350HT/400HB	370LHT/400HB									R260
Denmark	R350HT					R260					
Poland	R350HT					R260					
Hungary	R350HT					R260					
Romania	R350HT					R260					

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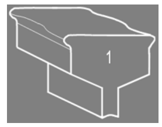
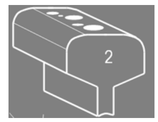
Restoring the rail profile

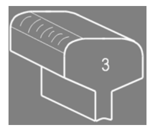
(1) Restore the longitudinal and transverse profile



(2) Remove surface damage



(3) Remove surface fatigue (RCF)



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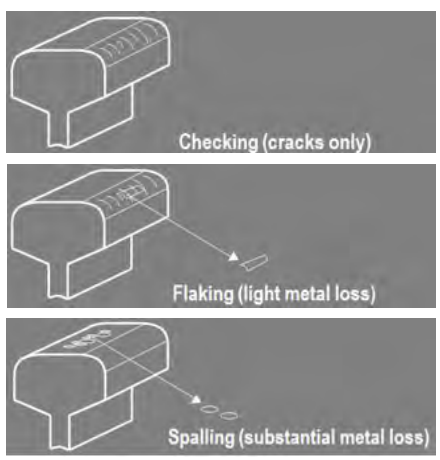
The rail fatigue



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Sleeper damage due to bad rail quality

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Subgrade degradation

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Subgrade degradation

- Subgrade degradation is mainly due to three factors:
  - Repeated traffic loading (affects subgrade stiffness)
  - weight of trains and
  - environmental factors including fine grained soils and high moisture.
- Subgrade degradation occurs in the presence of **water**. Water at the interface of ballast and subgrade leads to the formation of mud.
- Due to the cyclic loading by trains, the mud migrates into the ballast which becomes highly fouled.
- The slurry can block the drainage system, which enhances the subgrade bed weakening.

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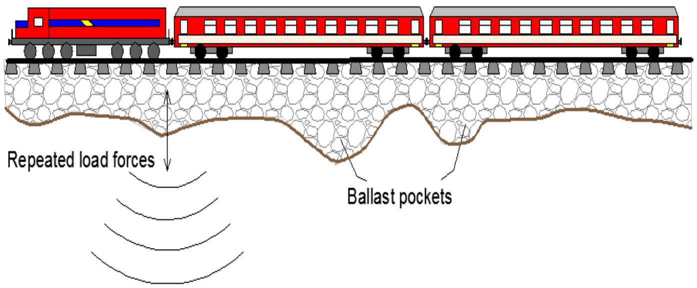
Ballast pocket formation



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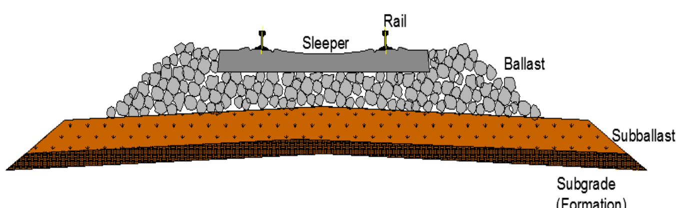
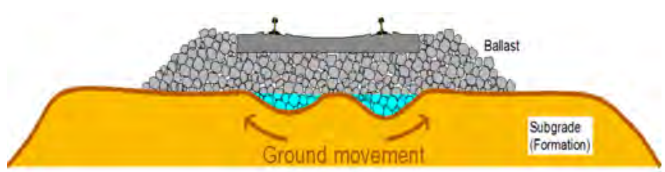


A typical cross section of a track (without ballast pocket formation)

the water is trapped in the ballast pockets, the ground begins to move sideward



Ballast pocket development: water trapped under rail

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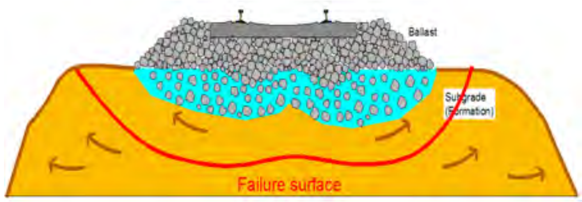
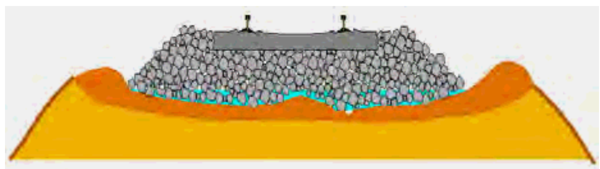


Bearing failure (with shear displacement).
Water saturated track structure



Subgrade squeeze, subgrade deformation

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Water trapped in a ballast pocket is a major contributor to many "soft track" situations

since most of these failure modes involve water, drainage improvement is almost always part of the remedy

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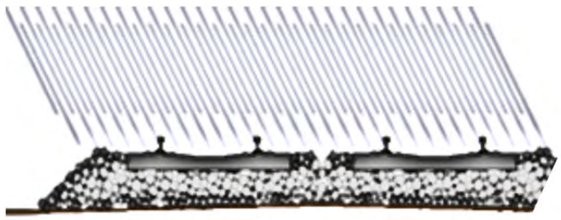
Track drainage



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Track drainage

There are four principal sources of water to consider that can affect the track:

- Rainfall directly on the track structure.
- Surface water flowing toward and infiltrating the track structure.
- Water flowing within the track structure, e.g., within ballast pockets or fill used to construct the embankment.
- Groundwater.

Collecting and diverting surface water away from the track structure may be the **most cost-effective portion of any subgrade maintenance program**. The more water that is intercepted and diverted, the less water is available to infiltrate and potentially deteriorate the track structure.

Track drainage consists of two types:

- Surface drainage
- Subsurface drainage

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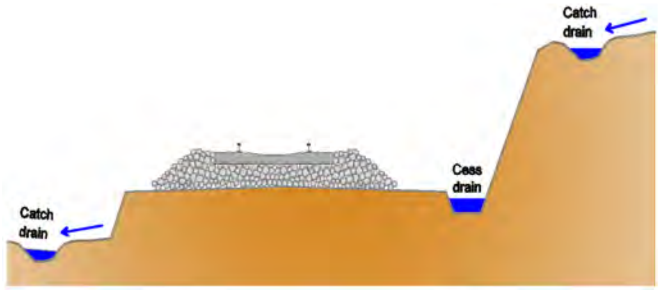
Surface drainage



Surface Drainage: Do's and Do Not's :

- DO divert water away from track
- DO keep cess drains clean and graded
- DO NOT let water pond
- DO NOT let water infiltrate the embankment

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Subsurface drainage

Subsurface drainage is necessary for maintaining the integrity of the track subgrade (formation) and ensuring the stability of earth slopes

Subsurface drainage is used for:

- drainage of the track structure
- controlling of ground water
- the draining of slopes.

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A slope before the construction of a track

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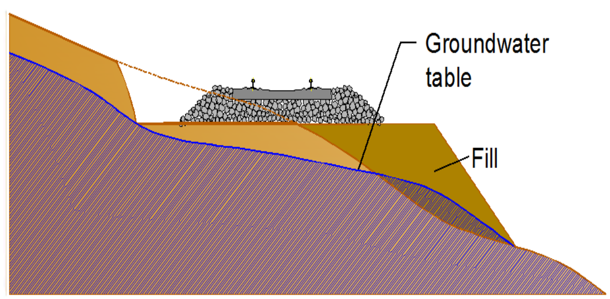

Groundwater elevation in fill before installing trench drain

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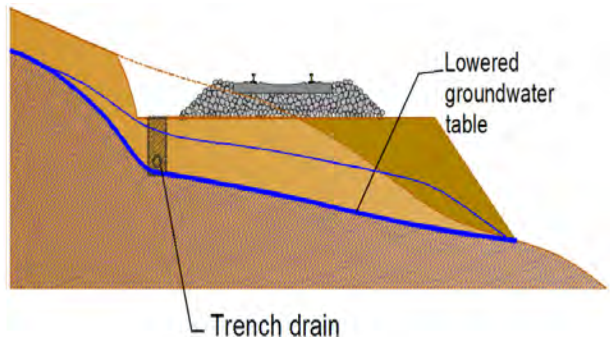

High groundwater condition causing embankment instability. Lowered groundwater condition resulting from trench drain installation also depicted

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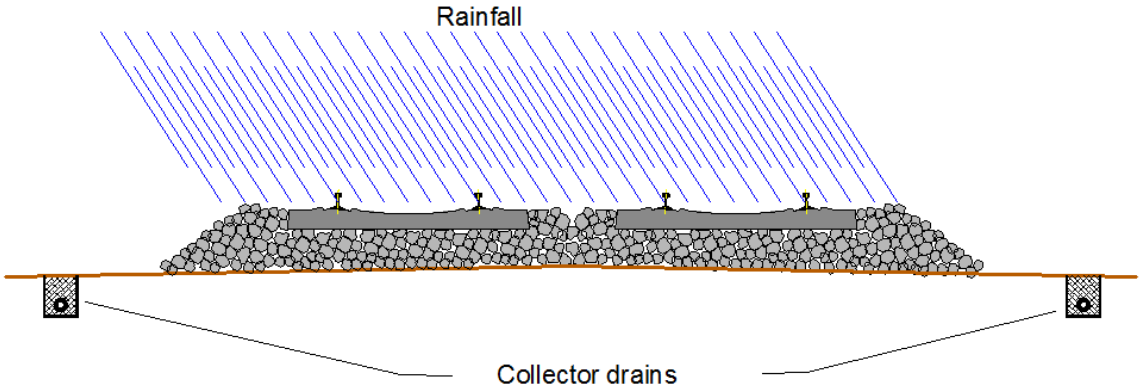
The functioning of subsurface drains



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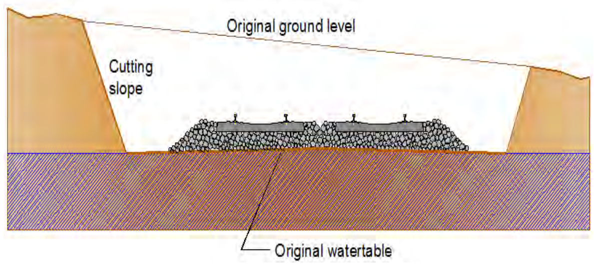
Lowering the water table (1)



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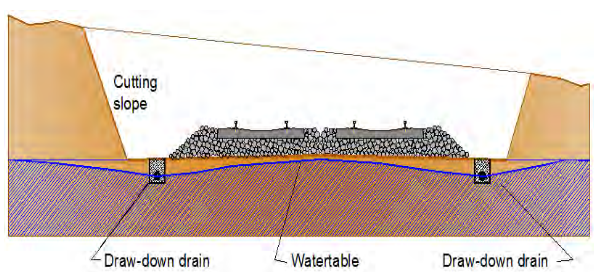
Lowering the water table (2)



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Indicators of pure drainage

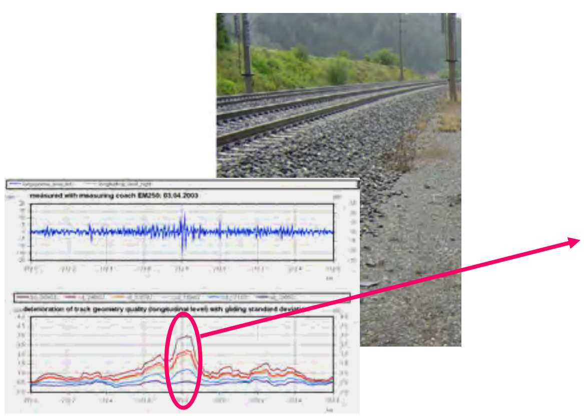
Wet ground near or on the embankment

Ponded water adjacent to track

Water pounded in ditch and wetland plants

77

Track geometry faults due to poor drainage(1)



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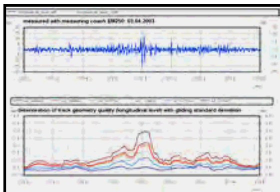

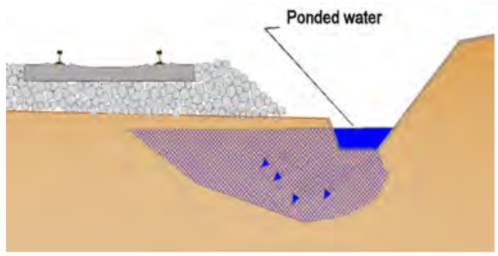

The ponded water infiltrates in the ground, with a local variation of the track stiffness, leading to a track softening at that location

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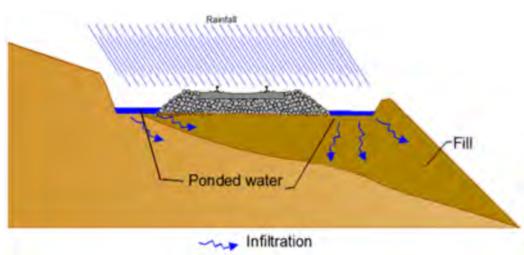
Failure due to poor drainage: Infiltration and embankment failure



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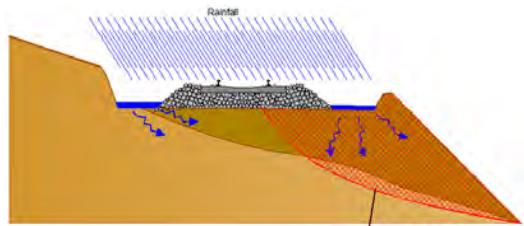

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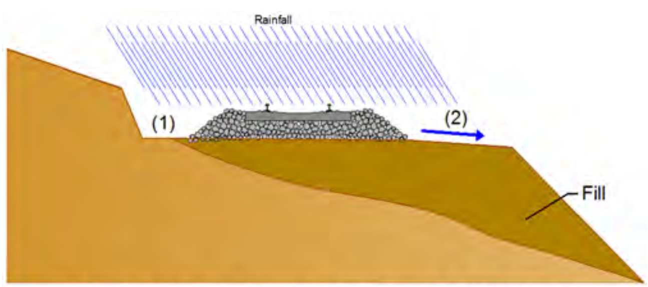
The solution…..



(1) Clean cess drain, provide adequate slope to flow the water along cess drain, dlean or add culverts, etc.

(2) Slope cess to drain. Do not concentrate flows

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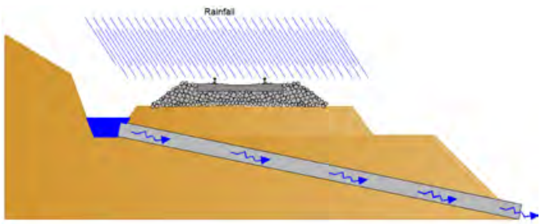
Embankment failure resulting from impounded Water



A good functioning culvert

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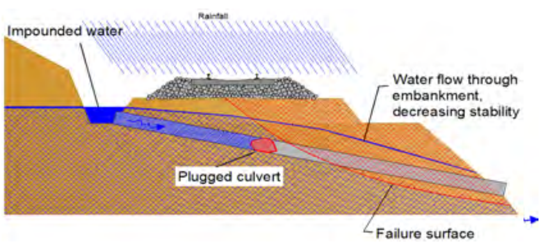
- *Embankment failure resulting from impounded Water is possible when no culvert is installed, or the culvert is plugged, so that the impounded water cannot flow away.*
- *The water flows through the embankment, decreasing stability which can lead to a failure surface*



Embankment failure resulting from impounded water

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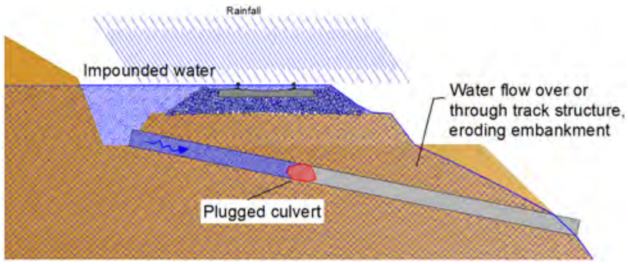
Erosion of embankment slope by water flowing over the embankment



In this case, the culvert is plugged or no culvert installed, the impounded water is in the level of the rail/sleeper. Water flow over or through the track, eroding embankment

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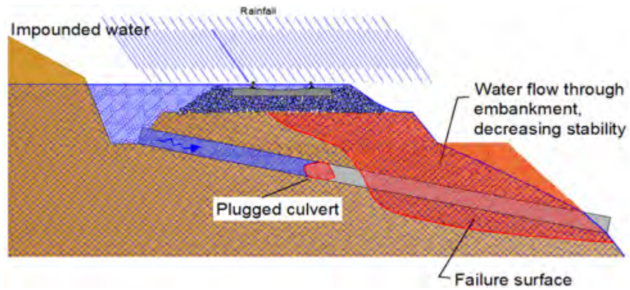

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Keep in mind.....

1. Water is a major contributor to soft track ... and the key to reducing the occurrence of soft track is ... ...**DRAINAGE**
2. … Water trapped in a ballast pocket is a major contributor to many soft track situations …
3. Proper surface drainage is probably the least expensive and most easily implemented measure for preventing soft track problems or improving performance of soft track areas ...

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Bad examples

Cess drain plugged by old ballast.

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Electrification pole and cable channels in the cess drains, hindering the water flow (drainage). Danger of pounded water.

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Renovation of a track in a railway station.
The track is laid in a "vessel". Water cannot be drained.

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Track quality

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"**Quality is not an act, it is a habit.**" *(Aristotle)*

"**Quality is never an accident; it is always the result of high intention, sincere effort, intelligent direction and skilful execution; it represents the wise choice of many alternatives.**"
William A. Foster

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- Trains have to run on time, and a basic condition is that the **quality of the track and other infrastructure objects is sufficient**.
- Most of the physical systems and their components **degrade/fail over time**. This affects the performance of the system and can lead to system failures. **Failure during operation can be costly, e.g. loss of service, property and even life**.
- The track engineer when he constructs, renews or maintains a track is of course aiming to deliver a track of high quality: but how does the quality affect the costs and the service life of the track?

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Quality and safety

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Quality and safety

What track is safer?

Quality has nothing to do with safety!!!

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Quality has nothing to do with safety!

Track maintenance has to be executed before track becomes dangerous: before it reaches the safety limits.

There should be always a safety “buffer”.

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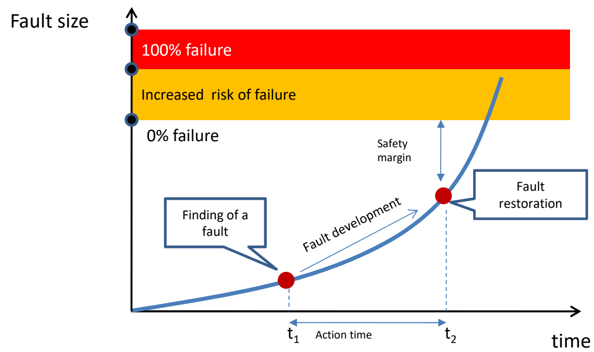

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Quality has nothing to do with safety!

Track maintenance has to be executed before track becomes dangerous: before it reaches the safety limits.

There should be always a safety "buffer".

It is obvious that reaching at a limit value related to safety, we have to execute maintenance immediately.

The urgency of intervention is mostly dictated by economic aspects.

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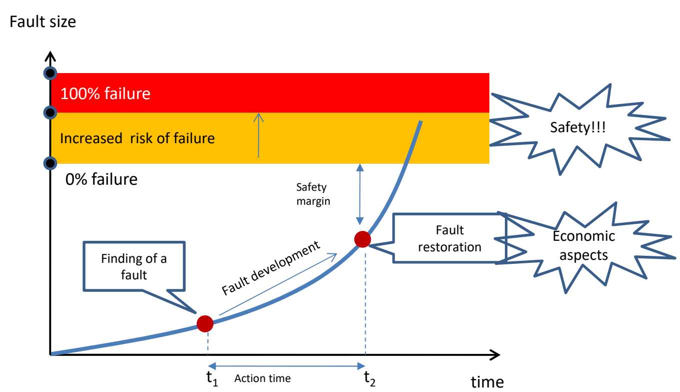

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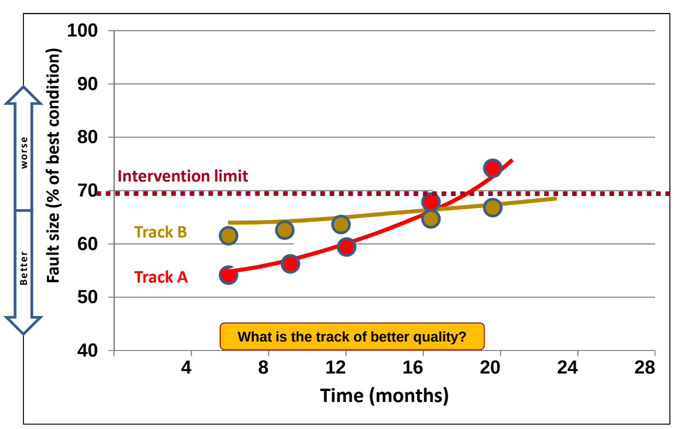
The track behaviour over time



Track quality is described by the current quality status and its behaviour over time!

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The importance of high initial quality

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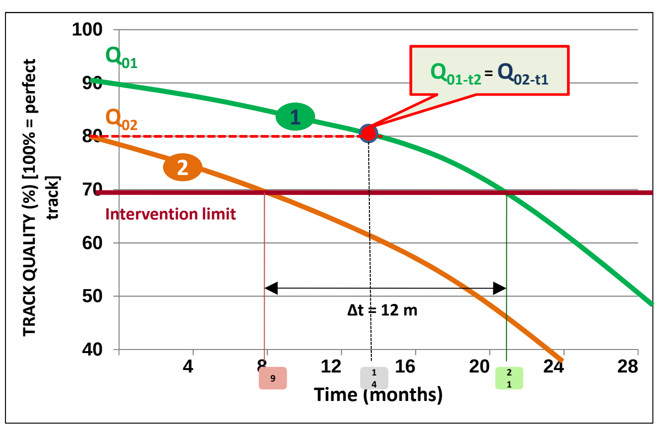
The importance of good initial quality (1)



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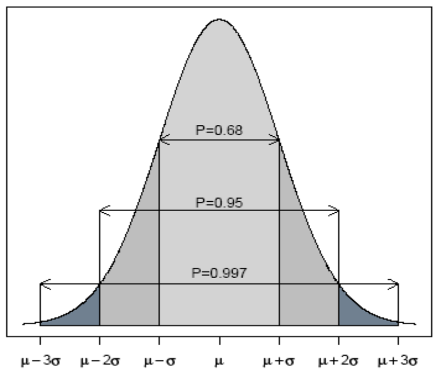
Some statistics
(needed next…)



P = probability
μ = mean value
σ = standard deviation

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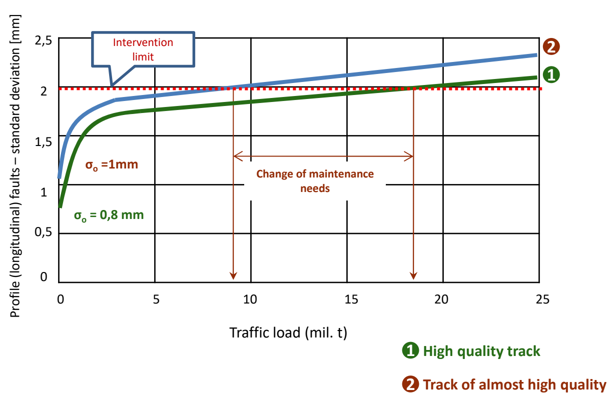
The importance of good initial quality(2)



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- The degradation rate of the track is like a typical fingerprint.

- The initial quality of a track determines its behaviour over time.

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Mathematical models for predicting the track quality

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The track deterioration model

Experience:
Good track behaves well (deteriorates more slowly)
Poor track deteriorates faster

⇩

Deterioration depends on the (initial) quality level:
Track behaves according to its quality

⇩

$$Q = Q_o \cdot e^{b \cdot t}$$

e = Euler number = 2.7182….
b = deterioration rate
t = time

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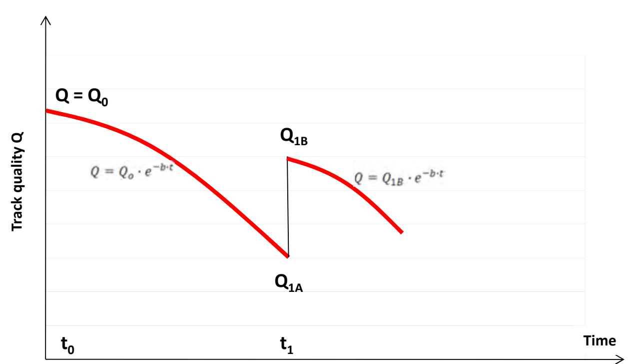
The development of the track quality(1)



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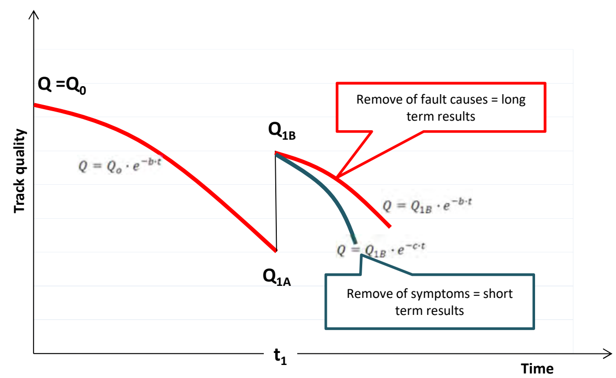
The development of the track quality (2)



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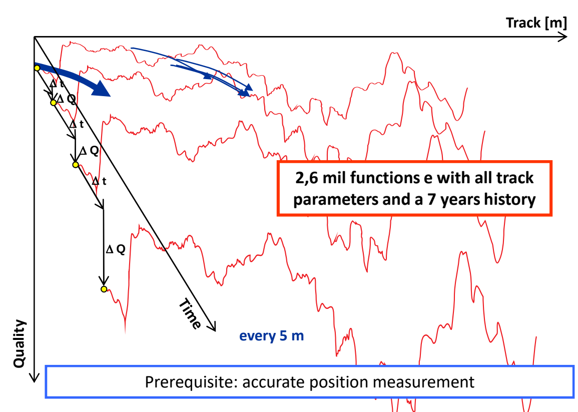
Track quality development (at ÖBB)



Source: Prof. Peter Veit, Technical University of Graz, Austria

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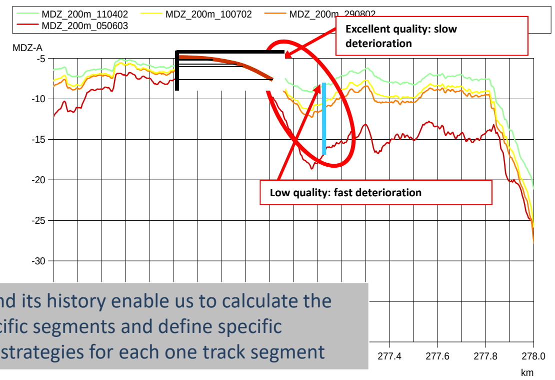
The analysis of the track behaviour



The current track condition and its history enable us to calculate the deteriorating factor b for specific segments and define specific investment and maintenance strategies for each one track segment

Source: Prof. Peter Veit, Technical University of Graz, Austria

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We noticed that

- Track geometry **is not a static situation, but a dynamic process**

but

- The development of the track geometry quality is more or less **known and can be predicted.**

Is there a possibility to act against the deterioration of the track quality?

The answer will follow….

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Parameters affecting the track quality over time

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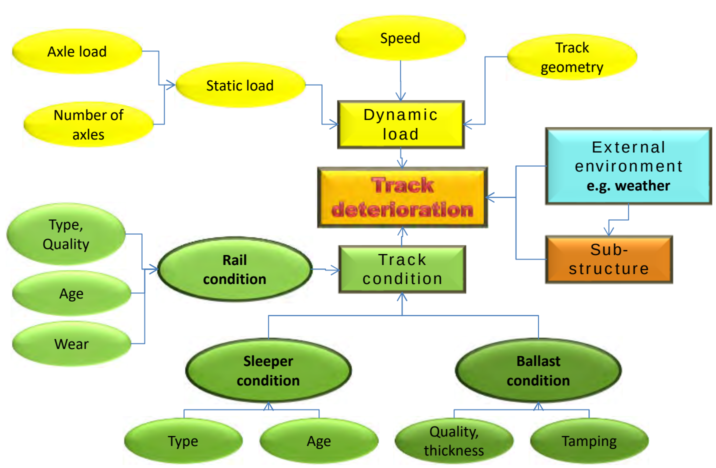

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**PART 3:
INTRODUCTION TO TRACK
MAINTENANCE**

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In the past …..

Today …..

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A historical background for maintenance

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The transition of a manual-labour-based economy to machine-based manufacturing

- In the early times when wooden and stone tools were made, the execution of certain works aimed to keep them in a good working condition. Maintaining those tools required nothing more than very **elementary skill**.

Axe heads found at a 2700 BC Neolithic manufacture site in Switzerland, arranged in the various stages of production from left to right.

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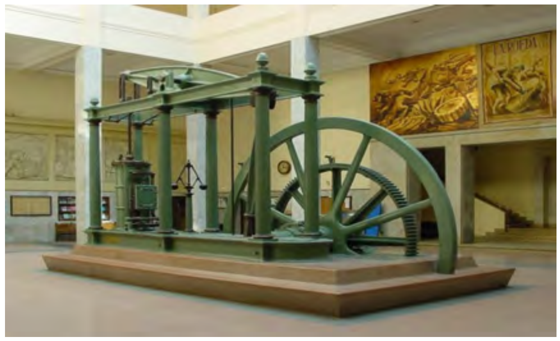
- In the later part of the 1700s the previously manual-labour-based economy transformed gradually into machine-based manufacturing.



Watt's steam engine at the lobby of the Higher Technical School of Industrial Engineering of Madrid

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The industrial revolution and the need for inspection and maintenance

- The development of high-pressure steam engines started with Richard Trevithick, from around 1800. High steam pressures brought about the need for increased safety awareness, resulting in periodic inspections to assess general condition and integrity.

Preserved British steam-powered fire engine – an example of a mobile steam engine. This is a horse-drawn vehicle: the steam engine drives the water pump

Successful maintenance was based on **skill**

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Starting the mass production

- The dominating maintenance policy in the time period up until the Second World War, was **run to failure**

Successful maintenance was based on skill and technical knowledge.

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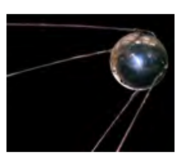
The period 1945-1960

- The competition of the Americans and Russians led inter alias to the space race, with the success of the various space programs heavily dependent upon **reliable operation** of equipment for given periods.
- Failure prevention became critical to ensure continued output and reduce cost and losses. Economic viability of a plant became dependent on the capability to predict the failure, and to prevent it by doing the relevant maintenance during off-peak periods.

The launch of Sputnik 1 marked the start of the Space Age (on October 4, 1957)



Launch of Apollo 11 spacecraft to the moon on July 16, 1969

In the period 1945 -1960, maintenance was characterized by a need for **skill, technical knowledge**, and **preventive and planning capabilities**.

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The period 1960 – now

- Since the 1960's, the concept of "Reliability Centered Maintenance" (RCM) was initiated by the "Federal Aviation Agency" in the USA.

  There was a need for a **"total approach" to maintenance** – in other words the examination of what is
  - the most appropriate mixture of maintenance types
  - for a given equipment type,
  - in a given operating context.

- This "most appropriate mixture of maintenance types" is often called the "**maintenance strategy**", applying the most appropriate mixture of preventive, detective, corrective and adaptive tasks in order to get to the most favourable balance between cost and availability / reliability.

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The need to a physical asset management

- A number of disasters forced industry and regulatory authorities to seriously re-think what the minimum requirements for good physical asset management are.
- On July 6, 1988 the Piper Alpha disaster in the North Sea happened. A public inquiry conducted by the British government under Lord Cullen and performed combustion/fire tests to investigate possible sources of ignition.
- Lord Cullen's recommendations were either taken up in legislation or became industry standards.
- So **Publicly Available Specification number 55 (PAS 55) was born**, with the first release published during April 2004.

The Piper Alpha disaster (July 6, 1988)

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The maintenance objectives

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The maintenance objectives

Issue	Description	Target
Safety	Probability for accidents	• As low as possible
Comfort	Comfort refers both to passengers and freight as well as to the environment (noise and vibration).	• Highest comfort for passengers and freight, • Minimum impacts to the environment
Availability	The availability of the track depends on failures and speed restrictions.	• Availability as much as possible
Economy	A low quality track is a very costly track, since the track deterioration affects both track and trains. At the same time maintenance is expensive.	• A cost effective track

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- Optimization of maintenance is needed to have a track of high performance. For optimal maintenance the task of highest priority and importance is to take the right measure at the right time.
- This task requires
  - **complete knowledge about the current condition of the track** and also the
  - complete **knowledge** about the **influence** and the **effectiveness of the different types of maintenance on the track**.

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- **Decisions** about maintenance are based today on
  - measurements of important parameters which are analysed to give knowledge about the condition of the track
  - knowledge about the deterioration behaviour of the track (from models and/or skilled engineers)
  - regulations,
  - budget constraints

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Track condition monitoring

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MEASURING TRACK PERFORMANCE

"Measurement is the first step that leads to control and eventually to improvement. If you can't measure something, you can't understand it. If you can't understand it, you can't control it. If you can't control it, you can't improve it« **(H. James Harrington)**

"You get what you measure. Measure the wrong thing and you get the wrong behaviours« (John H. Lingle)

"You cannot manage what you cannot measure"

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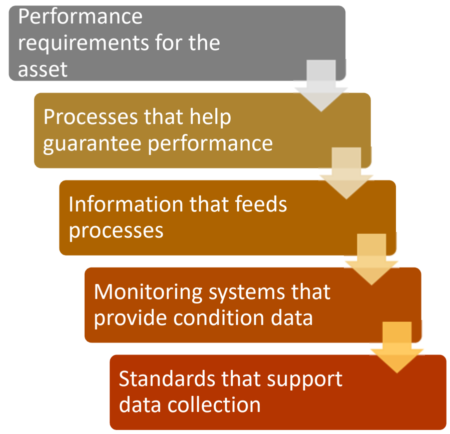
A top-down approach for track condition monitoring

- Infrastructure Managers in order to improve their performance,
  - must **take the right decisions** and
  - **control their processes**,
  - supported by the **right information analysed** intelligently,
  - based on the **right monitoring data collected wisely**, and
  - applying the **right standards**



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Monitoring as part of the maintenance strategy (1)

Maintenance Strategy	Maintenance actions	Monitoring System (track condition information)
Example 1: Very small deteriorations of the track geometry allowed.	• High-frequency maintenance actions	• Monitoring at high frequency • High accuracy of the information
Example 2: Maintenance strategy based on a good knowledge of the track geometry deterioration	• Clear intervention levels are set by the IM • Maintenance executed just before danger limits are exceeded	• Monitoring only at intervals in the order of magnitude of deterioration time, • the required accuracy can be slightly lower than in Example
Example 3: No clear maintenance strategy and / or no deterioration analysis is possible or available	• timely maintenance measures	• high accuracy and condition information in small time intervals may be needed

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Monitoring as part of the maintenance strategy (2)

Maintenance Strategy	Maintenance actions	Monitoring System (track condition information)
Example 1: Very small deteriorations of the track geometry allowed.	• High-frequency maintenance actions	• Monitoring at high frequency • High accuracy of the information
Example 2: Maintenance strategy based on a good knowledge of the track geometry deterioration	• Clear intervention levels are set by the IM • Maintenance executed just before danger limits are exceeded	• Monitoring only at intervals in the order of magnitude of deterioration time, • the required accuracy can be slightly lower than in Example
Example 3: No clear maintenance strategy and / or no deterioration analysis is possible or available	• timely maintenance measures	• high accuracy and condition information in small time intervals may be needed

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The monitoring as part of the maintenance strategy (3)

Maintenance Strategy	Maintenance actions	Monitoring System (track condition information)
Example 1: Very small deteriorations of the track geometry allowed.	• High-frequency maintenance actions	• Monitoring at high frequency • High accuracy of the information
Example 2: Maintenance strategy based on a good knowledge of the track geometry deterioration	• Clear intervention levels are set by the IM • Maintenance executed just before danger limits are exceeded	• Monitoring only at intervals in the order of magnitude of deterioration time, • the required accuracy can be slightly lower than in Example
Example 3: No clear maintenance strategy and / or no deterioration analysis is possible or available	• timely maintenance measures	• high accuracy and condition information in small time intervals may be needed

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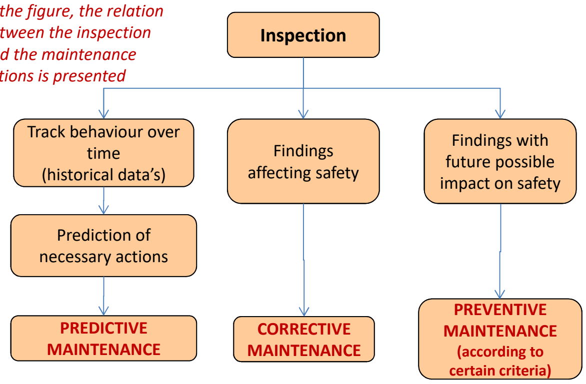
Track inspection

- Track inspection
  - Provides the necessary knowledge for the track behaviour, and
  - Provides important information for planning the maintenance

In the figure, the relation between the inspection and the maintenance actions is presented



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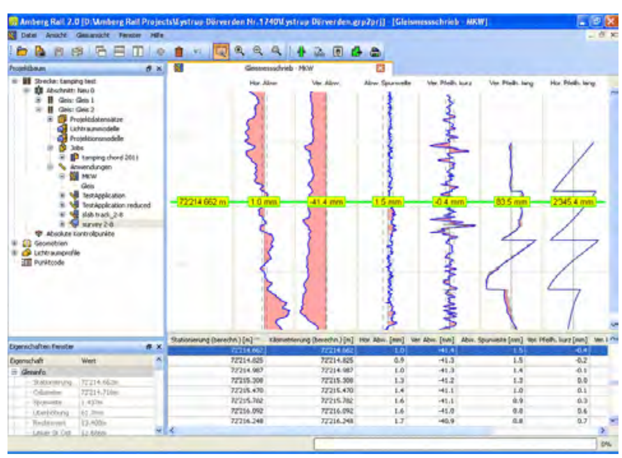
Mobile devices



The powerful Track Geometry Record software module offers extensive options for outputting track geometry reports.

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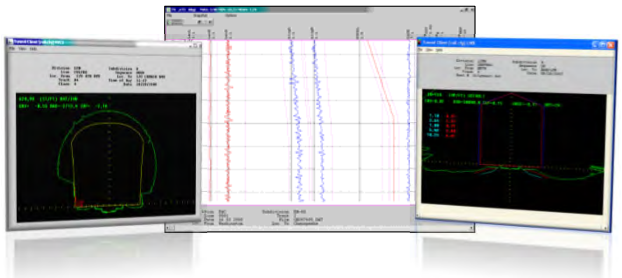
Track recording car



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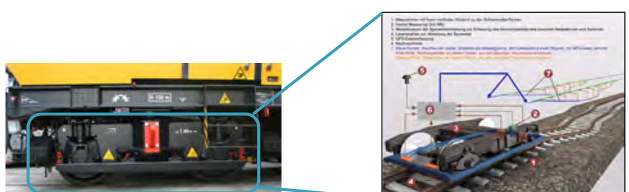

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Types of maintenance

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Types of maintenance

- There are many general types of maintenance strategies, such as
  - **Run to Failure Maintenance (RTF)**
  - **Preventive Maintenance (PM)**
  - **Corrective Maintenance (CM)**
  - **Predictive Maintenance (PDM)**
- Any combination of these strategies can apply in practice to the asset (the track). The process of "**developing a maintenance strategy**" is all about:
  - Defining an intelligent and functional way of determining the appropriate types of maintenance,
  - Determining how often maintenance is to be done to our asset.
- These strategies would best contribute to the successful realization of the company's goals.

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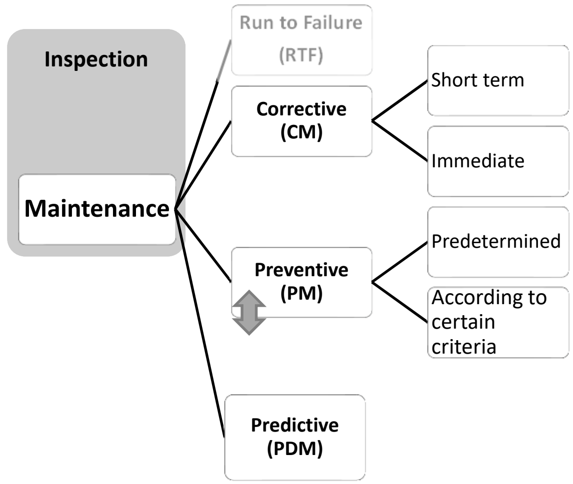

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Corrective maintenance

Corrective Maintenance

- corrective maintenance is defined as:
  "the maintenance
  - *carried out after recognition and*
  - *intended to put an item into a state in which it can perform a required function".*

- In this type, actions such as repair, replacement, or restore
  – will be carried out after the occurrence of a failure
  – in order to eliminate the source of this failure or
  – reduce the frequency of its occurrence.

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Preventive maintenance

Preventive Maintenance
"Fix it before it breaks"

- Preventive Maintenance is

  "the maintenance carried out at ***predetermined intervals*** *or according to* ***prescribed criteria*** *and intended to reduce the probability of failure or the degradation of the functioning and the effects limited".*

- By this type of maintenance, work is performed out at predefined intervals on a routine basis regardless of whether functionality or performance of the asset is degraded.
- These tasks require a relatively constant amount of labour and materials.

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Predictive maintenance

Predictive Maintenance
"If it ain't broke, don't fix it"

- **Predictive maintenance** (**PDM**) techniques help determine the condition of in-service equipment in order to predict when maintenance should be performed.
- Every rail infrastructure object has an expected lifespan, which is adjusted after observations of the track. This allows a rail Infrastructure Manager to predict the maintenance date in advance.
- This approach offers cost savings over routine or time-based preventive maintenance, because tasks are performed only when warranted.

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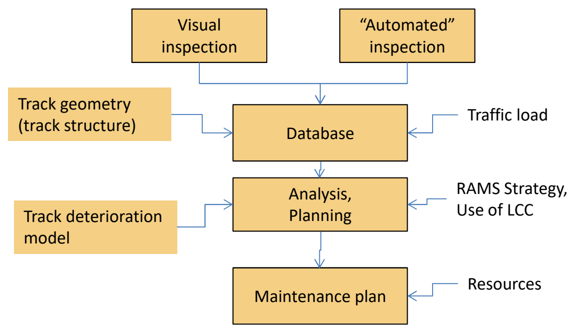
Process for planning predictive maintenance



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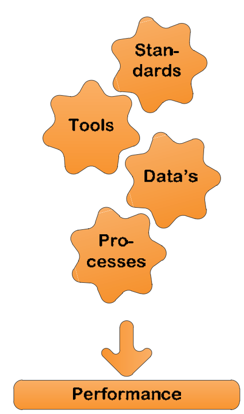
- The Infrastructure Manager aims at a high quality track not only when the track is new (high initial quality), but also during its life.
- In order to take the right decisions for maintenance he must have
  - right **standards** for monitoring the track condition
  - proper track **condition analysis tools**
  - **right track condition** data's (information) to be analysed, in order to understand the track behaviour.
  - **processes** to assure the proper working of the whole monitoring system.



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Track segmentation

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- For track maintenance an enormous amount of data is needed.
- To effectively manage and use all these data in order to analyse them and model the track behaviour, a solution is to divide the linear infrastructure into **homogenous segments with similar track characteristics and similar age and track "history"** (segmentation process)

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Chainage	10	10,1	10,2	10,3	10,4	10,5	10,6	10,7	10,8	10,9	11	11,1	11,2	11,3	11,4
Traffic load (t/day)	30.000	30.000	30.000	30.000	30.000	30.000	30.000	30.000	30.000	30.000	30.000	30.000	30.000	30.000	30.000
Radius [m]	<250	<250	<250	<250	<250	<250	<250	<250	<250	<250	∞	∞	∞	∞	∞
Rail profile	UIC50	UIC50	UIC50	UIC50	UIC50	UIC60	UIC60	UIC60	UIC60	UIC60	UIC60	UIC60	UIC60	UIC60	UIC60
Sleeperf type	WOODEN	WOODEN	WOODEN	WOODEN	WOODEN	BETON	BETON	BETON	BETON	BETON	BETON	BETON	BETON	BETON	BETON
Track construction	1985	1985	1985	1985	1985	1995	1995	1995	1995	1995	1995	1995	1995	1995	1995
Last maintenenace	2006	2006	2006	2006	2006	2006	2006	2006	2006	2011	2011	2011	2011	2011	2011
Subgrade	Type A	Type A	Type A	Type A	Type A	Type A	Type A	Type A	Type A	Type A	Type A	Type A	Type B	Type B	Type B
Characteristic places									Bridge				Turnout		
	SEGMENT 1					SEGMENT 2			SEGMENT 3	SEGMENT 4	SEGMENT 5		SEGMENT 6	SEGMENT 7	

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Asset management and the infrastructure manager

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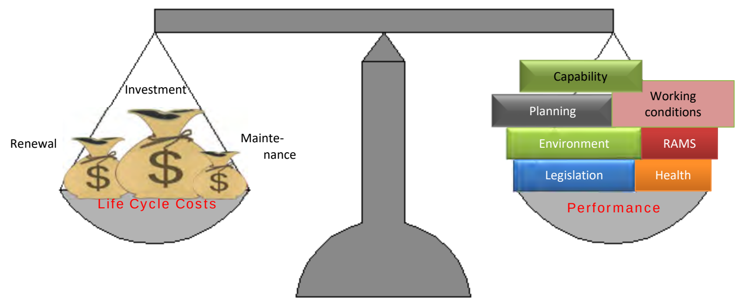
The Infrastructure Manager has to balance between cost and performance



If you don't apply asset management you will end up being considered either too expensive or not good enough

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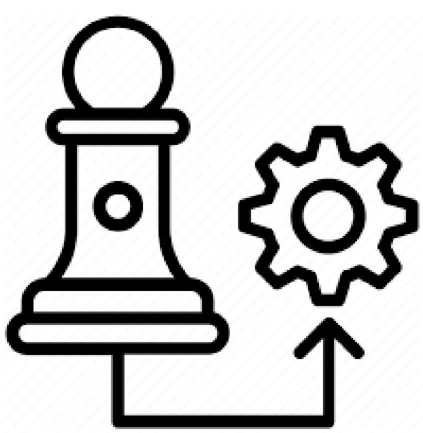

The various maintenance strategies and their impact on the service life of the track

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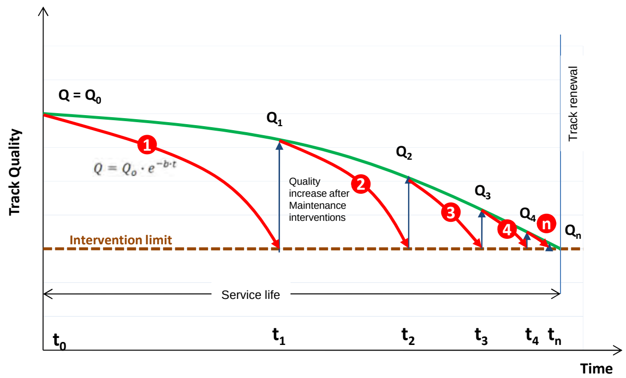
The service life of the track



*Service life of a track is "**the period of time over which the track provides adequate performance and function with anticipated maintenance but without major repair being necessary**".*

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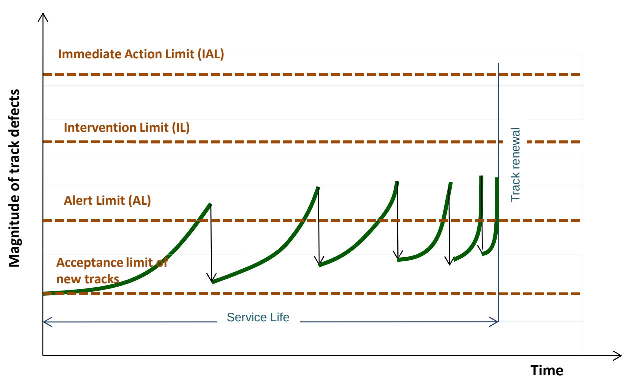
Maintenance Policy of InfraMan A



Track is maintained when the magnitude of track defects is between AL and IL	Track quality remains good	The longest possible service life is reached

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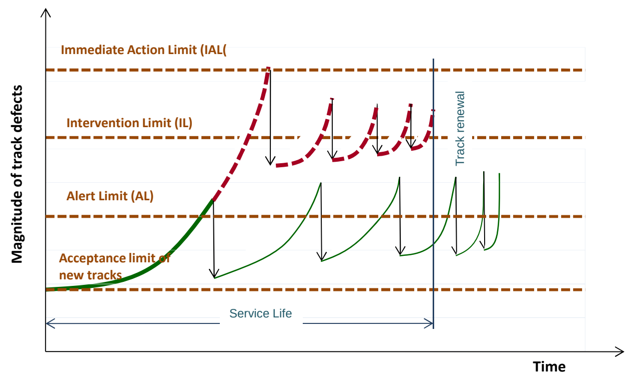
Maintenance Policy of InfraMan B



Track is maintained when the magnitude of track defects is between IL and IAL

Track quality is moderate

The service life of the track is shorter than that of IM A

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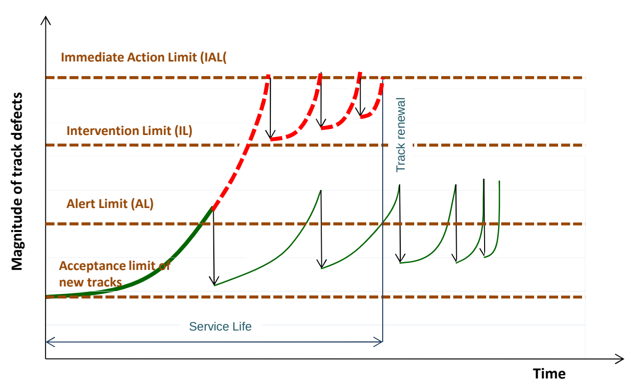
Maintenance Policy of InfraMan C



Track is maintained when the magnitude of track defects reach IAL

Track quality is not good, but safe due to a high maintenance frequency

The service life of the track is much shorter than that of IM A.

The track is very costly to maintain.

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Typical service life cycles

Action on the track	Traffic load	Frequency
Tamping	40-70 mgt	4-5 years
Grinding	20-30 mgt	1-3 years
Ballast cleaning	150-300 mgt	12-15 years
Rail renewal	300-1000 mgt	10-15 years
Timber sleeper renewal	250-600 mgt	20-30 years
Concrete sleeper renewal	350-700 mgt	30-40 years
Fastenings	100-500 mgt	10-30 years
Ballast renewal	200-500 mgt	20-30 years
Formation renewal	> 500 mgt	> 40 years

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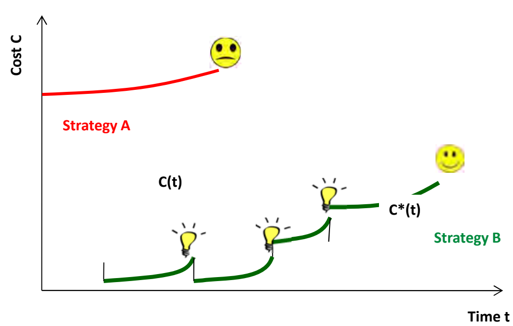
Extension of the track service life by applying proper maintenance strategy




Rational actions to reduce the maintenance costs and extend the service life of the track

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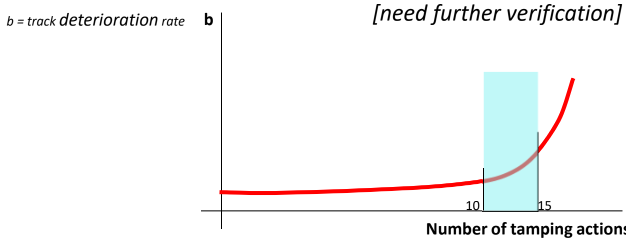
Tamping frequencies and their impact on track quality

Figure shows a nonlinear behaviour of b, to become critical after certain number of tamping actions (substructure in good condition)

[need further verification]



Source: Prof. Peter Veit

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The rational maintenance

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What does it mean effective (rational) maintenance?

> **"It's unwise to pay too much, but it's foolish to spend too little"**
> (John Ruston)

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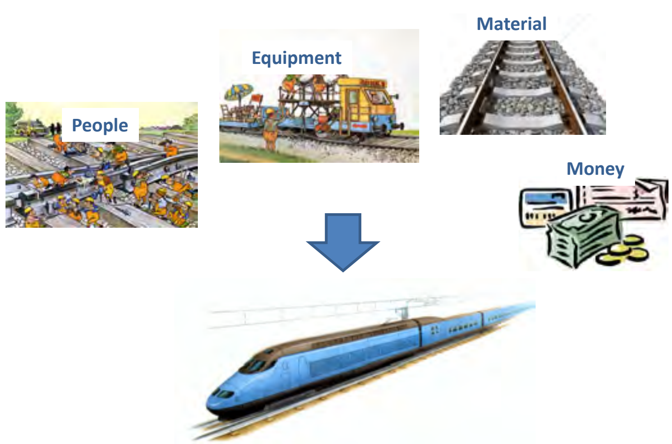
The resources



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- Rational maintenance is maintenance that achieves optimal results (maintenance of the asset to the desired functional performance level) with minimum possible resource consumption.

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The "old maintenance strategy" concept

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The “old strategy concept”

- Today, maintenance is largely empirical in the planning of maintenance in the short or medium term and executed
  - in a predetermined context (e.g. constant maintenance cycles) or
  - "extinguishing", i.e. interventions are executed to remove the symptoms of the faults rather than their causes.
- The result is the rapid recurrence of faults and constant and costly maintenance cycles.
- Another disadvantage of this practice is that maintenance is often not necessary (wasting of resources) and additionally in some cases it burdens the asset rather than benefits.
- Consequently, there is need for an effective maintenance strategy, which will ensure the required functionality of the track, starting at the design phase of the asset.

Is “old” maintenance strategy sufficient? If no, why?

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Evaluation of current (old) maintenance strategy

- QUESTIONS:

  Does the current maintenance strategy ensure
  - reliable maintenance?
  - cost effectiveness of maintenance?
  - high track quality for a long time (track durability)?
  - that maintenance will be done when really needed and that this will occur as often as it really should?

FINALLY, DOES THE CURRENT STRATEGY ENSURE THE EXECUTION OF A RATIONAL MAINTENANCE?

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The “future” maintenance strategy

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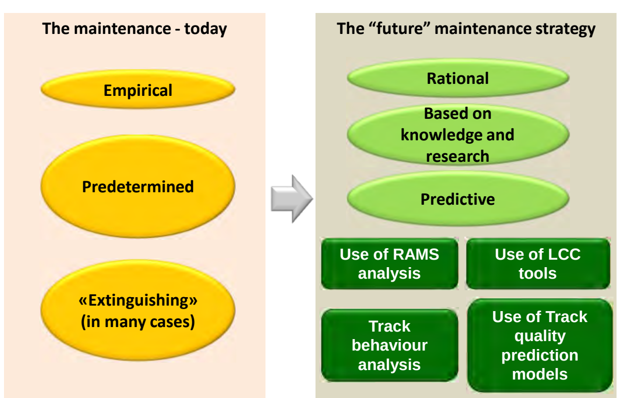
The rational maintenance strategy



Source: Prof. Peter Veit, Technical University of Graz, Austria

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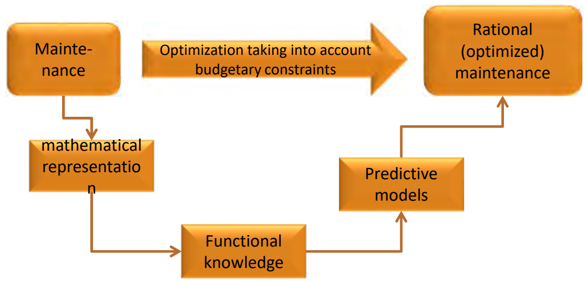
Transition procedure to a rational maintenance



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TOOLS FOR PLANNING A RATIONAL MAINTENANCE

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For the Infrastructure Manager, the key issues for the track maintenance are:

- 1st Issue: Which is the **best way** to maintain the track?
- 2nd Issue: How can we be assured, that over time the current maintenance practice is the **most effective** one?

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RAMS Analysis

THE 1ST ISSUE: Which is the best way to maintain the track?

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The 1st issue:

When should the track be maintained?

Which maintenance activities to perform?

How to disturb the railway traffic the least possible?

How to minimize hazards during execution of maintenance works?

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When should the track be maintained?
Reliability analysis:
Reliability

Which maintenance activities to perform?
Maintainability analysis:
Maintainability

How to disturb the railway traffic the least possible?
Availability analysis:
Availability

How to minimize hazards during execution of maintenance works?
Safety analysis:
Safety

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R

When should the track be maintained?
Reliability analysis:
Reliability

M

Which maintenance activities to perform?
Maintainability analysis:
Maintainability

A

How to disturb the railway traffic the least possible?
Availability analysis:
Availability

S

How to minimize hazards during execution of maintenance works?
Safety analysis:
Safety

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- When should the track be maintained?

  (**Predict "when" to take maintenance actions depending on the failure modes of the track**.)

  (Reliability Analysis)

- How can railway traffic be least disturbed?

  (**Predict the frequency and duration of track possession periods due to maintenance actions carried out on the track**.)

  (*Availability Analysis)*

R **Reliability**

A **Availability**

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- What maintenance activities should be performed?

(**Determine "what" maintenance actions need to be taken on the event of failures occurring on the track and "how" much time is taken to carry out those maintenance actions**.)

(*Maintainability Analysis)*

- How can the hazards be minimized during maintenance works?

(**Estimate the risk of carrying out different maintenance actions on the track in terms of severity and cost**.)

(*Safety Analysis)*

M

Maintainability

S **Safety**

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Proper RAMS analysis can help

- in effective maintenance planning of the track infrastructure and
- meeting maintenance objectives.

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Life cycle cost: LCC

THE 2ND ISSUE:

how can it be ensured that over time the current maintenance practice is the most effective one?

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EXAMPLE (simplified)

What car is cheaper?

Buy: 10,000 €
Maintenance: 400 €/year
Cost of immobilisation : 200€/year
Residual cost in 8 years: 0 €
Cost in 8 years:
10,000+8*(400+200)=**14,800 €**

Buy: 20,000 €
Maintenance: 200 €/year
Cost of immobilisation : 0 €/year
Residual cost in 8 years: 8,000 €
Cost in 8 years:
20,000+8*(200+0)-8,000=**13,600 €**

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What track (from point A to B) is cheaper?

V = 160 km/h
Min R = 650 m
Ballast: low quality
Construction cost : 5,000€/m

V = 160 km/h
Min R = 1000 m
Ballast: high quality
Construction cost : 8,000€/m

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Life Cycle Cost- LCC

- Life cycle cost – LCC) is the cost related to the service life of the system
- Regarding the track, it is (simplified):

LCC =

Investment cost

+ Cost of maintenance

+ costs of operational hindrances

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Causes of Operational Hindrances

Infrastructure	• Insufficient quality of the track ➔ permanent speed restrictions • investment or maintenance work executed • unexpected failures (catenary breakage, rail breakage, signal failures, …)	Planned
Infrastructure	• unexpected failures (catenary breakage, rail breakage, signal failures, …)	Unplanned
Operation	• extension of the station stops • delayed trains entering network at border station • slow driving trains • defect train on the track	Unplanned
Others	• accidents	

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Experience:

Good track behaves well (deteriorates more slowly)

Poor track deteriorates faster

⇩

Deterioration depends on the (initial) quality level:

Track behaves according to its quality

⇩

$$Q = Q_o \cdot e^{b \cdot t}$$

LCC = **Investment costs** + **Maintenance costs** + **Operational hindrances**

Source: Prof. Peter Veit, Technical University of Graz, Austria

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Why use LCC?

- LCC gives emphasis on enhancing economic competitiveness by working for **the lowest long term cost of ownership** which is not an easy answer to obtain.
- There are typical problems and conflicts observed in most companies, when different groups of interest in the company have different criteria for taking decisions
- Management is responsible for harmonizing these potential conflicts under the banner of operating for the lowest long term cost of ownership.

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Typical problems and conflicts in most companies

Group of Interest….	…. and the only criteria considering
Project Engineering	minimize capital costs
Maintenance Engineering	minimize repair hours
Production	maximize uptime hours
Reliability Engineering	avoid failures
Accounting	maximize project net present value
Shareholders	increase stockholder wealth

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- **LCC can be used as a management decision tool for harmonizing the never ending conflicts between the various groups of interest, by focusing on facts, money, and time.**

- LCC is important for engineers to help think like MBAs and act like engineers!

In this respect, LCC can be seen as an **engineering economics technique**.

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Conclusion (RAMS, LCC Analysis)

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Are there any tools for planning of an effective maintenance?

- Proper RAMS analysis can help in the effective design of track maintenance.
- Life cycle cost (LCC) can help in selection of correct materials, choice of a maintenance methodology etc.

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- **RAMS analysis** based on the condition of the track will help to identify various alternative ways / methods of maintenance.
- **LCC analysis** can help to optimize the efficiency of maintenance work that emerged from the analysis of RAMS, related to cost.
  The cost estimates based on LCC analysis can help in predicting the cost of various track works throughout the whole service life of the track - not the only on short term.

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Guiding principles for an effective track

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Guiding principles for an effective track

1. Try for an initial high track quality
2. Keep water away from the track surface
3. Make an effective design and as simple as possible
4. Maintain when required
5. Be environmentally astute
6. Train staff
7. Respect and keep historic values

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Innovative solutions to reduce maintenance needs

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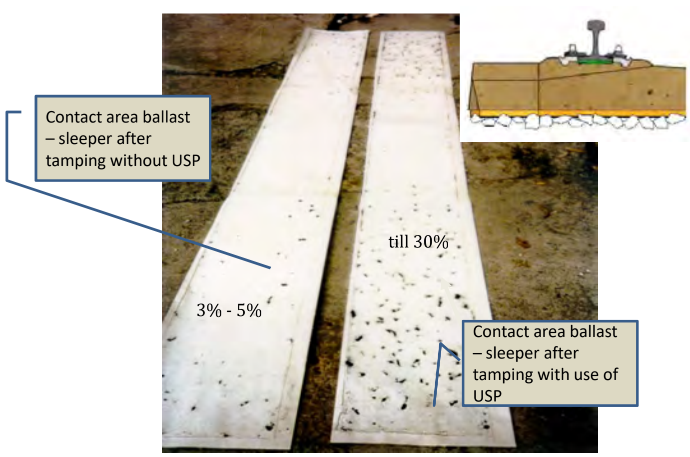
Use of Under Sleeper Pads (USP)



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Use of Under ballast mats

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Use of frame sleepers (Rahmenschwelle)

Frame sleepers provide a continuous seating of rails, and much higher lateral resistance

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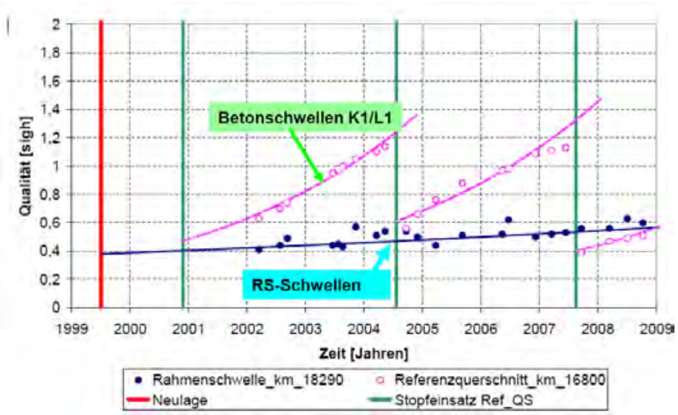

Source: Prof. Peter Veit, Technical University of Graz, Austria

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INVESTMENT AND BUDGETING DECISIONS

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Investment and maintenance

The sole purpose of **investing** is a **high initial quality**.

The sole purpose of maintenance is to assure that
this initial quality leads to an **extension of the service life of the track**.

Investment and maintenance should be viewed as
elements of a **strategy for the superstructure**.

Lack of maintenance,
delayed or improper maintenance of the track
devalues the investment,
as far as decreasing its service life

Source: Prof. Peter Veit, Technical University of Graz, Austria

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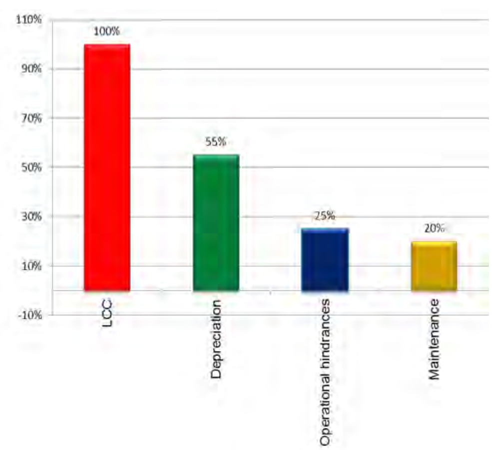
The structure of LCC



Remember: $$Depreciation = \frac{Investment\ Cost}{Service\ Life\ of\ the\ Track}$$

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Strategies to decrease the LCC

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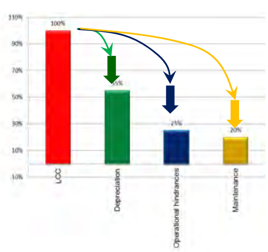

$$Depreciation = \frac{Investment\ Cost}{Service\ Life\ of\ the\ Track}$$

- Strategies to decrease cost:
  1. Decrease of the depreciation cost. It is possible by decreasing the numerator or increasing the denominator of the fraction (see equation), that means by decreasing the LCC of the track or by increasing its service life.
  2. Decrease of the cost of operational hindrances. Better planning of maintenance, ~~reduce train circulation~~?
  3. Decrease of track maintenance costs: optimized maintenance strategy

Due to the fact that depreciation is the dominant cost factor, a strategy for a prolongation of the track service life is the most effective one

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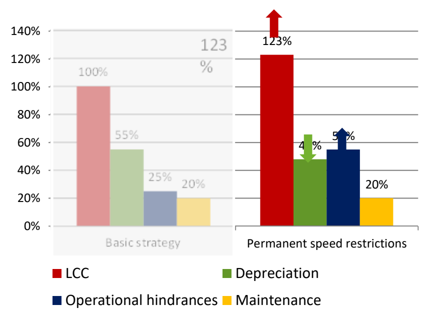
Investment decisions



Case 1: Decrease of the depreciation cost – Increase of the service life of the track, by accepting its degradation: **Speed restrictions** as a result

- LCC increases: lengthening the useful life of the line against quality is uneconomical

$$Depreciation = \frac{Investment\ Cost}{Service\ Life\ of\ the\ Track}$$

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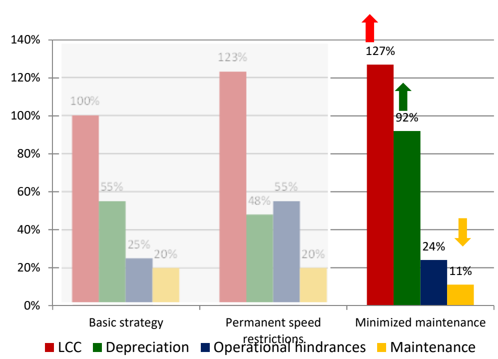

Case 2: Reduce maintenance

- By reducing the required maintenance, the track service life is reduced,
- thus increasing the cost of depreciation (the denominator of the fraction
- in the equation is decreased), i.e. by reducing the available budget for maintenance

$$Depreciation = \frac{Investment\ Cost}{Service\ Life\ of\ the\ Track}$$

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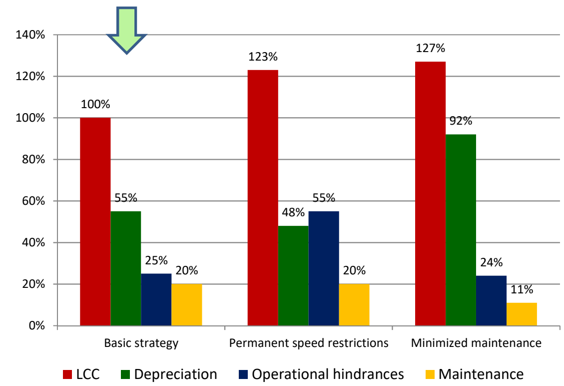
Conclusions



A track with good quality is the most economical one

But only a proper maintenance can ensure the benefits of a track with an initial good riding quality

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Conclusions for effective track maintenance

Source: Prof. Peter Veit, Technical University of Graz, Austria

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Parameters influencing the service life of the track

The service life of the track depends on

- The magnitude and wavelength of the track geometry faults, due to the fact that they are influencing the forces acting on the wheel and so to the vehicle
- the Rolling Stock quality (e.g. wheel flats) that have as a result high forces due to the wheel/rail interaction
- Other parameters (e.g. track drainage, quality of track components – mainly ballast)

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Other parameters affecting the service life of track

Bad substructure

…. Due to low bearing capacity

…. Or insufficient drainage for long time

IRR of substructure rehabilitation = 35% (!)

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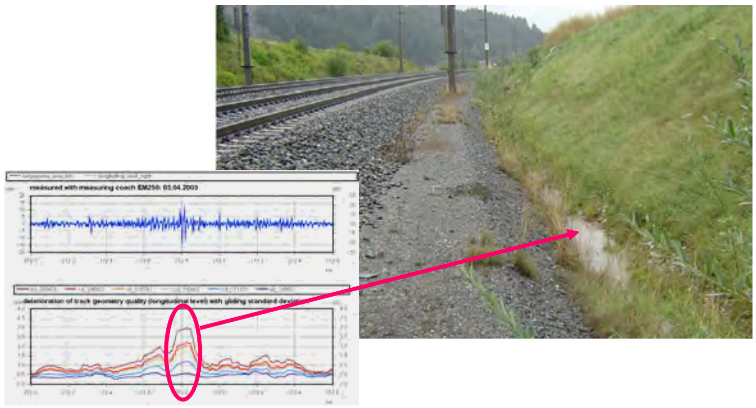
Insufficient drainage



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If substructure and/or drainage are not matching quality requirements, track optimization is impossible

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So, for a good track quality……

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Precondition Nr. 1: Good substructure

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Precondition Nr. 2: Good drainage

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Precondition Nr. 2: Good ballast quality

- LCC depends mostly on depreciation, that means the service life of the track.
- **Ballast of bad quality decreases the service life of the track by 20% and even on switches by 30-40%!!!**

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Precondition Nr. 2: Homogenous segments

Bad practice:

Sleeper type

- Bi Block Sleepers U31
- Bi Block Sleepers U31
- Wooden Sleepers
- Beton Sleepers B70
- Steel Sleepers

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PART 4: TRACK QUALITY – BAD EXAMPLES

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BALLAST DEPOTS

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BAD BALLAST QUALITY IN THE TRACK

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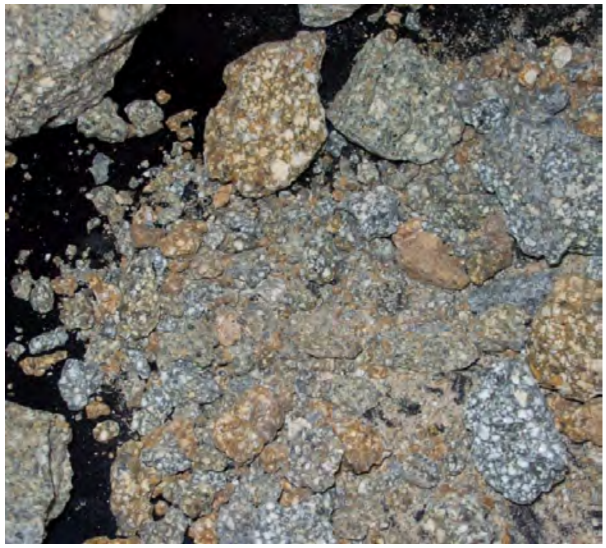

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BAD DRAINAGE

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POOR WORKMANSHIP

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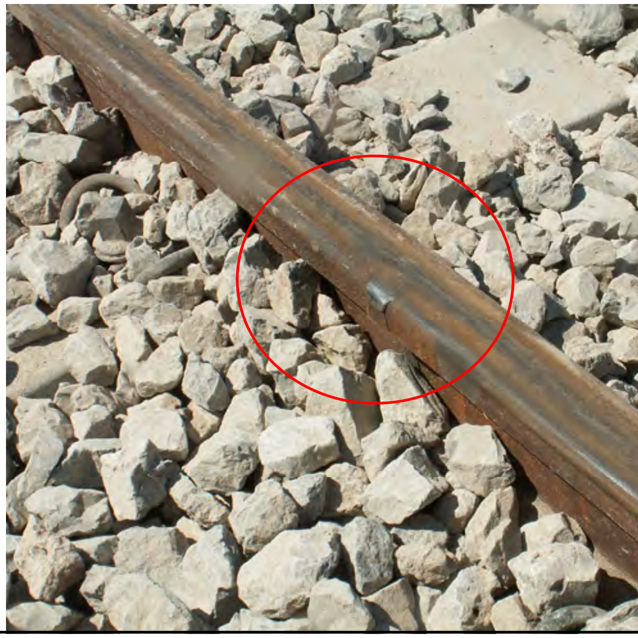


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