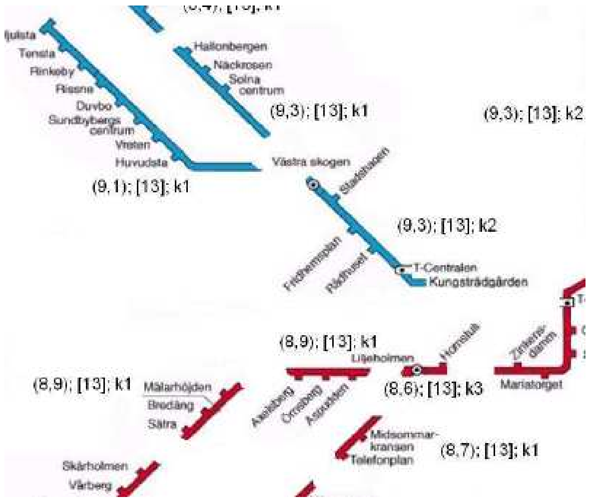
Long term evaluation of track deterioration -

application on the metro line in Stockholm



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Motivation

- **Owner directives - comprehensive**

In decision-making, Stockholm Public Transport (SL) must clarify the economical consequences of different alternatives (short and long time perspective), aiming at an economy in financial balance.

- **Owner directives - economical efficiency**

To obtain a low cost/pkm and high degree of usage it is important that new investments (*vehicles*) make use of the recourses (*infrastructure*), maximizing the benefit with respect to the total cost.

The current situation

- The audit* assesses that SL […] has not ensured a satisfactory control of costs. SL's own calculations show rapidly increasing costs – which most likely will accelerate due to planned investments.

- The audit* also believes that SL's budget does not fully recognizes the impact from planned and realized investments on the company's future operating costs.

*Stockholm County Council, audit report Nr 12/201.

Scope

SL plans for new metro vehicles from 2016 and has initiated evaluations of:

- Track loading (deterioration) – MiW Konsult
- Track and vehicle maintenance (partly MiW Konsult)
- Impact of vehicle characteristics – MiW Konsult
- Track investments (partly MiW Konsult)

- Traffic analysis and prognosis – SL
- Substructure (geotechnical) – external
- Bridges and constructions – external

Developing a three-step analysis

1. System characterization

- Maintenance,
- Traffic,
- Network
- Scenarios

Classification and forecast

2. Track mechanics

- Load collective

Load probability and expected influnce

3. Track deterioration

- Track damage<>costs
- Costs<>LCC per traffic scenario

Macro scope per mechanism

1. System characterization

- Mainly track, vehicle and economic data but also maintenance principles, regulations and quality targets

- Six years of maintenance costs were extracted.
  Target: define a set of costs believed to be driven by traffic loads (incl. historic variations).

- Costs for *rail grinding, track leveling and lining, inspection, lubrication, sleeper and fastenings, ballast, switches and crossings, rails, track, superstructure* and more...

- Templates for distributing lumped cost and renewal costs from estimated periodised life-time cost for replacing components.

1. System characterization – *track, vehicles and traffic*

- The network was distributed in rail profiles, sleeper types, rail pads etc. Substructure properties was estimated based on composition.

- Track quality and wear of rails were evaluated separately.

- Axle load distribution all over the network, depending on vehicle type, passenger occupancy and frequency on different relations.

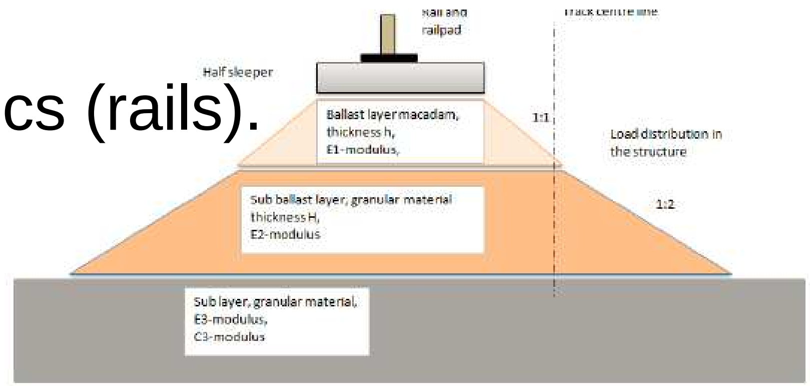
- Traffic data from SL:s prognosis until 2025 = passenger and vehicle volumes.

2. Track mechanics – *analysis and risk identification*

- Evaluate if and under which conditions the track and structure may support the range of expected traffic loads.

- Evaluate the track response for a defined load case (related to the model exponents):

  - Evaluate different geotechnical assumptions.
  - Winkler foundation.
  - Linear elastic fracture mechanics (rails).



3. Track deterioration

Evaluate the influence of changed traffic loads.

1) Basic formula has been used for separate damage mechanisms (based on TRV-model*):

   Damage ⇔ $\text{load}^{\text{exponent(mechanism)}}$
   Damage ⇔ cost expenditure on mechanism

2) Track quality deterioration is divided on different substructures, reflected in different load dependencies.

*Former Banverket report LABan 2007:31

3. Track deterioration
- *break-down on component level*

- Settlement and ballast (tunnels/open air).
- Fatigue, deformation and wear of sleepers and fastenings.
- Internal rail fatigue, crack propagation.
- Overall track superstructure
- Rails, plasticity, welds
- a.o.

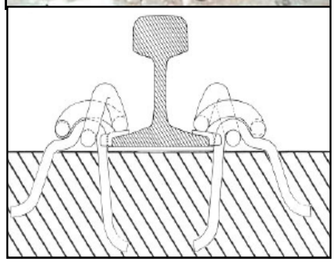
Load exponents for above were based on judgements of the load-response from the track mechanics and ”rule of thumb”, such as plasticity being related to square root of change in normal load etc.

Results (part 1)

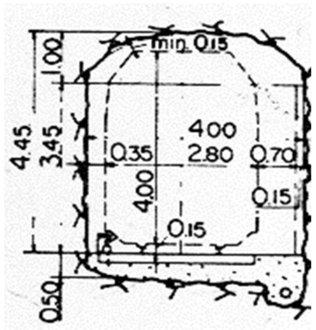
Identifying crucial components (need replacement/reinforcements to withstand increased loads):

Vulced fastenings, approx. 550 track-m

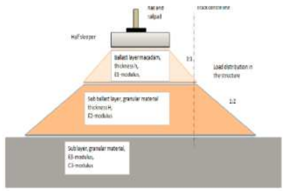
Elastic track, approx. 700 track-m



Old Pandrol fastening

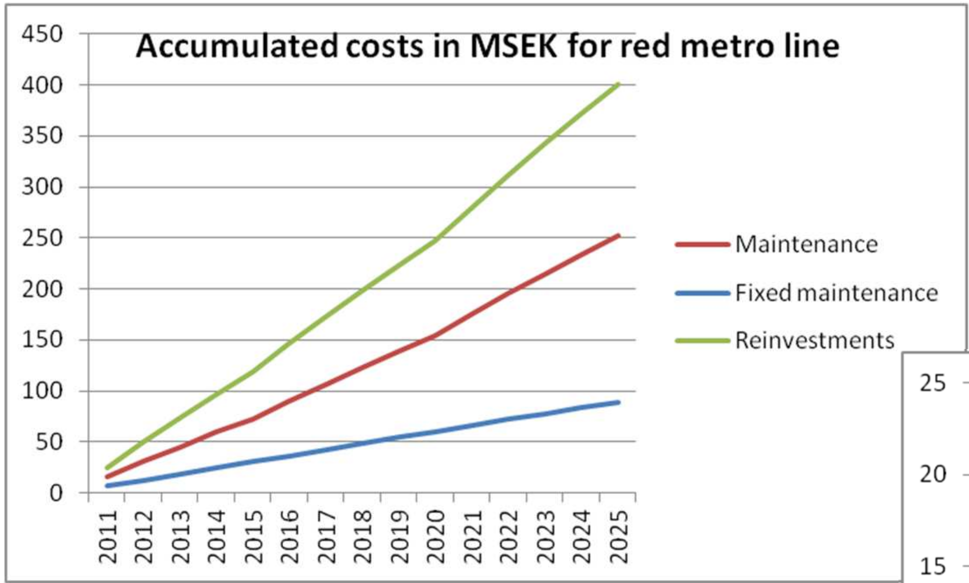


Thin ballast layers and large sleeper spacing (locally).

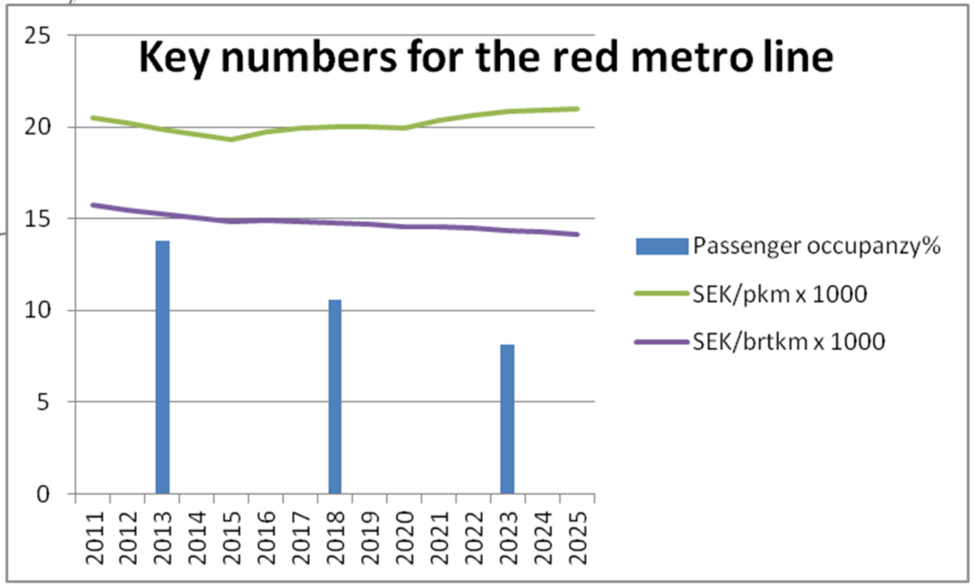


Weak subsoils (locally).

Results (part 2 – based on SL:s traffic scenarios)



- Traffic prognosis 2011-2025
- C30 from 2016 with 2t higher axle load (1 t due to vehicle)
- Detailed load case depending on relations, time of day etc.



Above: Fixed – non traffic-dependent
Right: SEK = traffic dependent, excl reinvestments

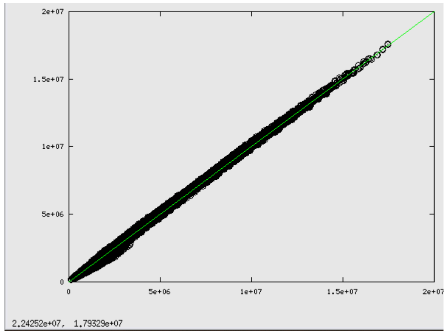
Using the results

- The results have been presented to SL and broken down on different levels.

- These results may be used by SL in the planning process. However, it is not straight forward to recalculate the result using other load cases etc. The results also rely on a theoretical ”C30”-vehicle and mixed traffic with CX.

- Therefore, about 40 000 combinations of parameters were varied in the model and then a multi non-linear regression function was adapted.

- This approach makes it possible to calculate the present value of track deterioration cost over 30 years, corresponding to a defined traffic volume.



A simplified track deterioration model is implemented in the C30 evaluation model

The winning tender will be the one assessed to be the most economically advantageous to the purchaser, based on :

P = tender price = Σ(18 different obj, incl **0.75* Track deterioration cost ("C")**)

"C" reflects track maintenance and renewal cost during the lifetime of vehicles, according to:

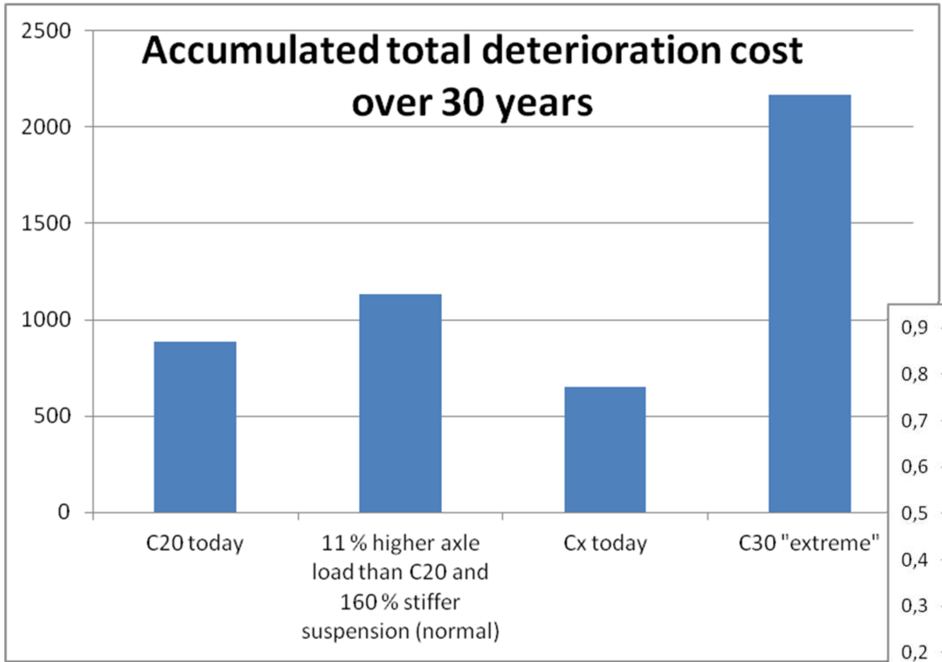
$C=f(f_1,f_2,T)$ *Tonnage (different traffic scenarios may be reflected)*

$f_1=P^x+aP^y$ *Axle load polynomial (0<x,y <1.5)*

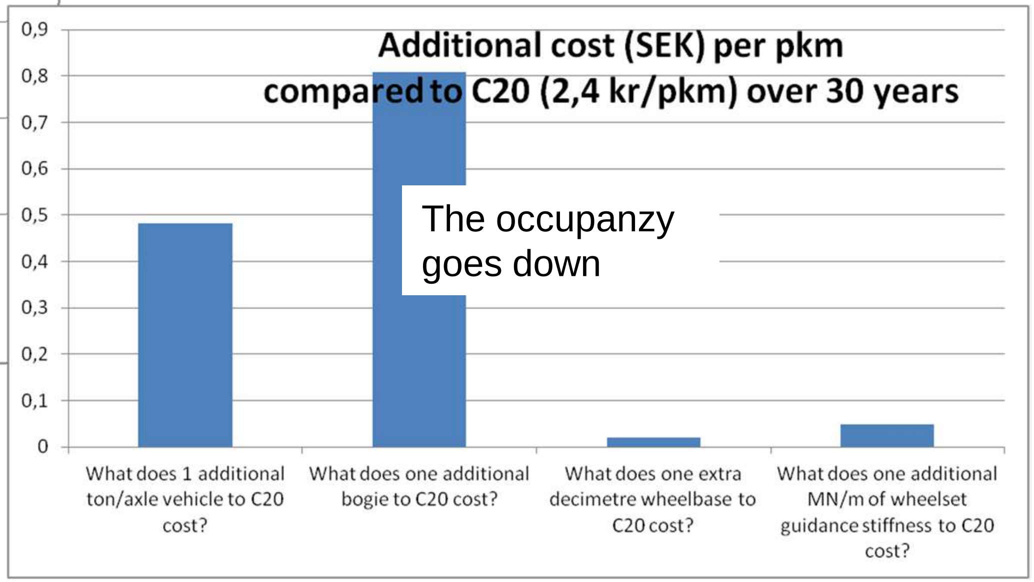
$f_{2(\ldots)}=g(a_{bL},n,P)*f(k_x) + h(a_{bL},n,P)$

Weighing functions depending on primary spring stiffness and other

Sensitivity analysis based on the simplified model - Fixed net-traffic volume over 30 years



Reference case is traffic today being able to carry an increased fixed passenger volume



Conclusions and next steps regarding the C30 evaluation

- Track deterioration cost has (with a factor 0.75) been included in the comparison price together with many other different price objects.

➢ Not possible to predict what will happed to the track and with the maintenance costs until a decision about the vehicle has been made.

- Bridges are not included in the model but treated according to a special procedure.

- Fundamental geotechnical questions are not included in the model but to some extent included in both the track deterioration model and the bridge procedure.

Remaining questions to be solved

- How to make sure to decide about track maintenance budget when deciding about vehicles?
- How to make track maintenance people aware of what to expect?
- How to follow up real maintenance work and maintenance costs compare to predicted? (N.B. UH2012 – Contractor fully responsible for track maintenance.)
- Bridges and geotechnical questions?!

➢ Should lead to further work regarding analyzing and improving of the track deterioration model proposed.

Additional reading

Öberg, J. *Maintenance cost and deterioration of the track superstructure on the red and blue metro line in Stockholm – referring to the years 2011-2025 and the introduction of a new vehicle type C30* [In Swedish: *Underhållskostnad och nedbrytning av spåröverbyggnaden på Stockholms röda och blå tunnelbanenät – avseende åren 2011-2025 och införande av fordonstyp C30*]. MiW Konsult AB, report 11105-1 v1.0, 2011-06-15.

Öberg, J. *Increased axle load on the metro lines in Stockholm – investigation of bearing capacity and stresses in the track* [In Swedish: *Ökad axellast på Stockholms tunnelbanenät – utredning av bärighet och påkänningar i banan*]. MiW Konsult AB, report 9103-1, 2010-02-04.

Öberg, J. *Technical background of the track deterioration cost model to be used for the evaluation of different rail vehicles on the metro lines in Stockholm*. MiW Konsult AB, report 11110-1, 2012-05-02.

Additional slides

How the simplified track deterioration model is implemented in the C30 evaluation model

The winning tender will be the one assessed to be the most economically advantageous to the purchaser, based on the following:

- P = tender price = Σ(18 different obj, incl **0.75* Track deterioration cost**)
- B = technical quality
- C = commercial quality

and calculated according to:

$$J = P + (Q_{max}*((B_{max}-B)/4)^2)+C$$

J = comparison price
P = tender price
Q_{max} = maximum price increment for technical quality
B = score obtained for technical quality
B_{max} = maximum possible score for technical quality
C = Increment due to commercial quality

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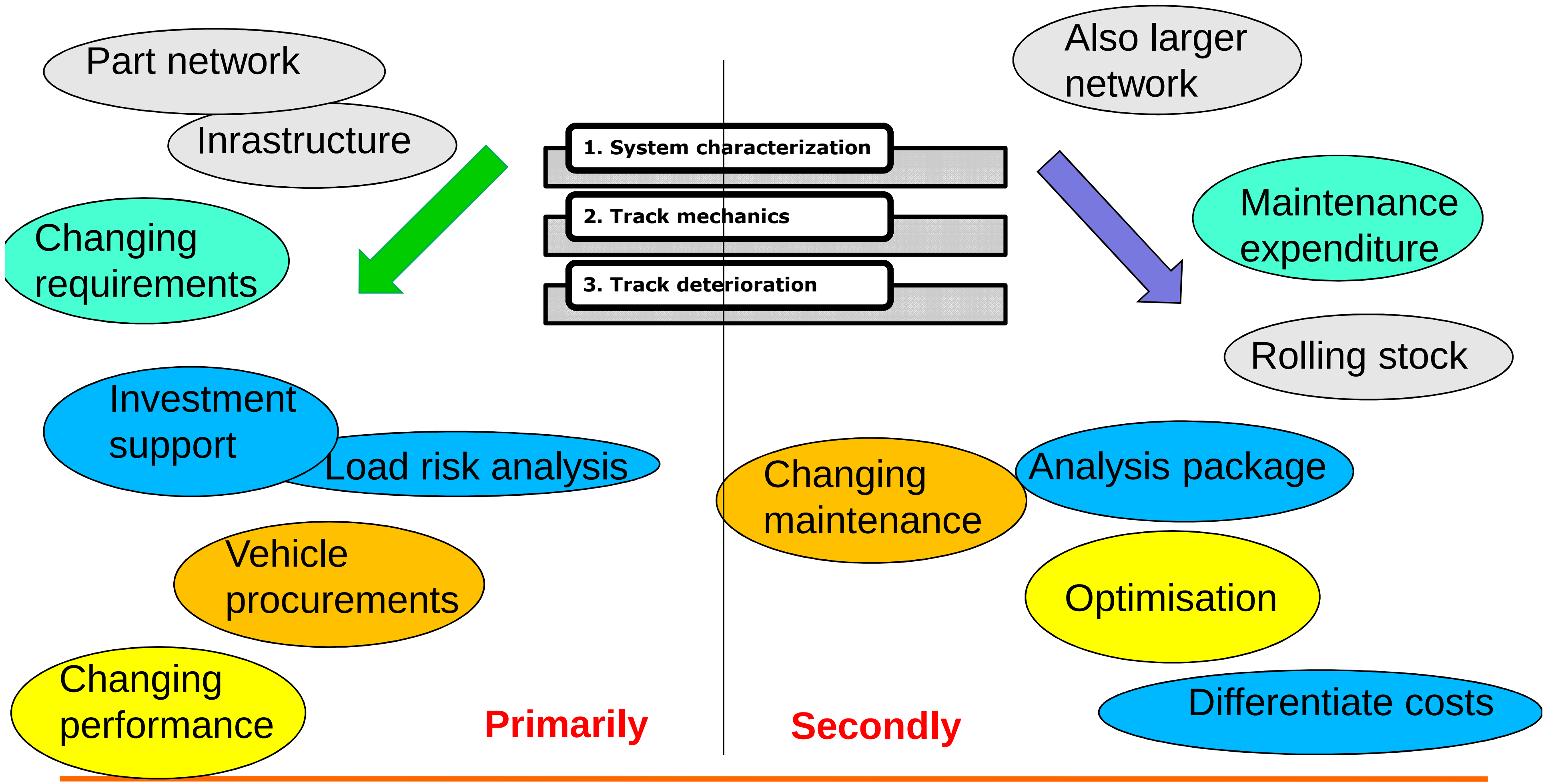
Why and when to use?



Uppdelning av grupp G2 – övrigt underhåll	*Skadeexponent för spårkraft*	*Tidigare vald skadeexponent*[6]	*Skademekanismer*
Sliper/befästn	0.8	2,5	Utmattning, deformation, slitage
Räler uh (dock ej ultraljud)	2.5	2,5	Inre utmattning, sprickbildning, rälbrott, hjulplatta
Räler skarvar	1.0	2,5	Fenbildning, slitage
Svets (dock ej ultraljud)	3.0	2,5	Utmattning, brott
Spår	1.2	2,5	Ovan nämnda samt skador på ballast
Spårväxlar (dock ej ytskador på räl)	1.3	2,5	Utmattning räl, utmangling, befästningar, slipar
Överbyggnad övr	0.5	2,5	Osäkerhetspost