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Chapter

Assessing Average Maintenance Frequencies and Service Lives of Railway Tracks: The Standard Element Approach

Stefan Marschnig and Peter Veit

Abstract

As track behavior varies in a wide range of service lives and maintenance demands must be specified. The Standard Element Approach provides a specification based on the most important boundary conditions influencing track behavior such as transport load, alignment, superstructure components as well as substructure qualities, and last but not least the functionality of the dewatering system. These parameters show several possible values. The mix of all of these parameter values describes tracks in the entire network. This clustering helps for decision making for strategic asset management: superstructure component use for different parameter sets, calculating average maintenance and renewal demands and thus the respective budgets for a sustainable track strategy avoiding or reducing backlogs. The Standard Element Approach works for all railway infrastructure assets, this chapter focuses on track in detail.

Keywords: track maintenance, track components, superstructure, track asset management, sustainability

1. Introduction

Asset Management aims for identifying and implementing a sustainable and cost-efficient track structure. Furthermore, this track structure needs proper maintenance in order to achieve a sustainable permanent way. However, the one "best track" does not exist as boundary conditions change. These conditions are described by different sets of parameters such as traffic load, subsoil condition, dewatering system, and many more. Thus every "best track" must be a sustainable solution for the given specific situation—sustainable from the technical perspective as well as from the economic one. This requires not just evaluating innovative technical solutions but also proving its economic efficiency, over the entire life cycle.

The evaluation needs a sound technical description of maintenance being then transposed into maintenance costs. The economic evaluation needs to give answer to the three main questions of asset management:
1. Which type of track is to be selected under certain conditions? (Investment strategy)

2. How to maintain this structure? (Maintenance strategy)

3. When should the entire track structure be reinvested? (Economic service life)

These questions cannot be answered separately as an investment strategy cannot be formulated without considering the maintenance demand, a maintenance strategy must be based on the specific investment, and the economic service life is a consequence of both investment and maintenance.

This results in a two-stage model: first, we need technical descriptions of different options describing investment, maintenance, and service life and thus track deterioration. Life cycle management is therefore a prerequisite for asset management. The second step is to transform the technical information into costs in order to identify the economically most sustainable solution from the different options. The presented Standard Element approach provides a strategic view and acts on average track behavior. To answer question 3 on project level, so for a specific track section somewhere in a network, the Standard Element approach is too general. In this case, we need to use on-site measurement data and deterioration function [1, 2]. The economic appraisal is similar.

Looking at the literature, we find a lot about the proper organization of maintenance within an asset management scheme [3–5]. The different options for applying maintenance as reactive, preventive, condition-based, or even predictive maintenance are well discussed in many papers. Besides these theoretical concepts, also maintenance scheduling for railway tracks is being analyzed and published [6–8].

Most scientific papers discuss track or component behavior, the wear- and damage processes, and the deterioration of components or the entire track. This is especially true for the ballast-related issues, mainly track geometry [9–11] and rail behavior [12–16]. While these papers study quality loss, maintenance is often not addressed. And if maintenance actions are covered, mainly the quality improvement is focused on [17–19] in order to identify if the maintenance action was successful or not. We also see papers dealing with proper intervention levels for different track maintenance actions [20–22].

However, maintenance frequencies for tracks facing different boundary conditions are rare and provide very rough and general figures. These maintenance frequencies are by far not sufficient to answer the questions of track asset management. Therefore, this paper delivers maintenance frequencies for varying boundary conditions, for different transport volumes, track radii, track components, and subsoil conditions.

2. Methodology

A Standard Element describes track behavior in its specific maintenance demands and service lives—based on different sets of parameters, different investment options, and its associated maintenance demand. The Standard Element approach was developed for cyclic track investment and maintenance but also can be used for permanent component exchange. Among the different options the most sustainable needs to be identified, finally in its economic efficiency.

One Standard Element describes the track behavior of one specific set of parameters in its investment, maintenance demand, and service life. All parameters
influencing track behavior in a relevant way, either the maintenance demand or the service life—or both, needs to be looked at. The relevant parameters must be identified. The entire network is clustered according to these parameters. The aim is to describe common situations precisely (Standard Element Approach). Individual cases are not pursued further within the framework of this method.

Every Standard Element is linked to a working cycle (Figure 1) consisting of the maintenance frequencies over the service life. Evaluating general track strategies demands analyzing different options of maintenance like minimized/reactive maintenance or preventive maintenance and their consequences on the service life. In the end, the working cycle linked to the Standard Element depicts the economically most sustainable option, a sufficient, mostly preventive maintenance, and the optimal service life.

The year zero shows the investment, followed by all planned maintenance actions including one line for small maintenance, which sums up all maintenance actions which are just reactive (e.g., rail breakages).

The core part of the Standard Element is the Working Cycle, describing maintenance demand and service life and thus track behavior for the given parameter set. This should be based on data and experience. It is generally carried out in working groups. Their members are decision-makers from the headquarter, technicians, and economists. Their knowledge is mainly based on a big amount of data. However, there is a second source of knowledge, the experiences of track engineers out at the track sections. Their knowledge is based on observation, does not fundamentally contradict data knowledge, but complements it in essential details. These two different sources lead to important discussions necessary for a proper definition of the working cycles.

The Standard Elements should cover the main part of the network. For verification, the number of kilometers of the various Standard Elements in the network must be calculated. Furthermore, the age of the sections is relevant. The verification of the working cycles is possible by comparing real investment and maintenance demand of the network with the demand described within the Standard Elements.

For identifying the most sustainable track solution a cost evaluation of all options is executed. Therefore, Standard Elements are transposed into time sequences of costs, starting in the year zero (year of investment) lasting until the next re-investment. The various options in general show different investment costs, different maintenance demand, and different service lives. Due to the different service lives the net present value cannot be used for ranking the options. The life cycle cost evaluation and thus a ranking of different options must be based on their average annual costs, including costs of fixing money. Within such an evaluation the cheapest option is the most sustainable one, as “cheap” is always taking all life cycle costs into account, from investment to next re-investment. Thus, the sustainable option requires an optimal balance of investment and maintenance and an optimal balance of maintenance and service life.

Based on verified Standard Elements, the most sustainable investment and maintenance options are identified for all relevant track situations in a network. This is also true for innovations, of course after a relatively short testing period.

Figure 1. 
Standard element including working cycle.
2.1 Clustering the network

2.1.1 Parameters

Within the Standard Element Approach “Parameters” are the boundary conditions that lead to certain track behavior and thus trigger the maintenance demands and service life. While some of those parameters are given, some are topics of track strategies.

The alignment of track is a major aspect when it comes to track maintenance demand. It is obvious that a curved track needs another maintenance regime or simply more maintenance than a straight track section. Consequently, service life is shorter on curved tracks compared to straight tracks.

The transport load is obviously triggering maintenance: the more trains operated, the higher the maintenance demand and the shorter service life.

Next to those two parameters hardly being influenced, the construction of the track itself defines another set of parameters:

The subsoil forms the foundation of a track and thus has a major impact on the amount of maintenance needed. Subsoil with sufficient bearing capability and a properly working water drainage system needs the least maintenance and delivers maximum service life.

The used track components are important parameters. Every single component goes along with either specific wear or damage phenomena or at least with different severances of those. The rail profile defines the durability of the rails. Smaller profiles lead to the necessity of through-going rail exchange in case of high transport volumes within the track’s service life. Rail steel grade drives both (side) wear in sharp curves and rolling contact fatigue phenomena in larger curves. The sleeper type, mainly concrete and wooden sleepers, but also steel sleepers in some cases and newly concrete sleepers with under sleeper pads (USP), plays an important role in ballast maintenance: the different types lead to changes in the sleeper-ballast interface, decreasing or increasing the contact pressure and thus ballast bed deterioration and consequently impact tamping needs. Ballast and subsoil quality directly influence not only track service life but also tamping demand. The same is true for the quality of the dewatering system.

2.1.2 Parameter values

For the parameters concerning superstructure, the values are simply the components to be used, for example, wooden sleepers or concrete sleepers. To keep the number of combinations low, parameter values might be restricted to some combinations. An example would be “49E1 rails on low loaded lines only”.

Values for the parameters “Subsoil” and “Drainage” are an issue as values are not available, especially for existing substructures. In case of executed subsoil rehabilitation, $E_{vd}$ values would be possible, but can also not cover the linked aspect of dewatering. Most infrastructure managers go for a “smart” characterization: “good” is derived from a situation in which superstructure quality and its maintenance are not influenced negatively by subsoil or dewatering topics, while “poor” would mean the other extreme.

Traffic load and alignment need clustering of discrete values. For higher traffic loads, a range of some 10 mio. Gross-tons per year (and track) is feasible looking at international experience with the Standard Element Approach. For lower traffic loads, smaller ranges are necessary though.
The topic of alignment of track is dealt with between the two extrema “straight” (no side wear of rails, rail surface failures, tamping due to restoration of cant, or similar occurs) and the minimum radius for continuous welding of rails (jointed rails lead to different track behavior and maintenance actions anyhow).

The “number of tracks” parameter with its values “single-tracked” and “double-tracked” is not decisive for track behavior in the overwhelming part of effects, but is in case of track work costs due to different logistics and track closure times, respectively operational consequences of such closures.

We summarized the most typical parameter values for mixed traffic networks in Table 1.

2.1.3 Parameter sets: The standard element

A combination of exactly one value for every parameter delivers the description of one technical situation within the network, one Standard Element. On the lift top corner in Figure 2, we see the coding according to Table 1.

Theoretically, there is an enormous amount of possible Standard Elements combining all parameter values. Practical use shows that some 100 Standard Elements help to cover 90 percent of a network being sufficient for achieving valid and robust values for maintenance and renewal.

<table>
<thead>
<tr>
<th>Transport Volume in Gross-tons per Year</th>
<th>Alignment</th>
<th>No. of Tracks</th>
<th>Rail Profile</th>
<th>Rail Steel Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;25 mio.</td>
<td>1</td>
<td>single-tracked</td>
<td>Xa</td>
<td>R200</td>
</tr>
<tr>
<td>15–25 mio.</td>
<td>2</td>
<td>double-tracked</td>
<td>49E1</td>
<td>R260</td>
</tr>
<tr>
<td>10–15 mio.</td>
<td>3</td>
<td>others</td>
<td>54E1</td>
<td>R320Cr</td>
</tr>
<tr>
<td>5–10 mio.</td>
<td>4</td>
<td></td>
<td>54E2</td>
<td>R350HT</td>
</tr>
<tr>
<td>3–5 mio.</td>
<td>5</td>
<td></td>
<td>60E1</td>
<td>R400</td>
</tr>
<tr>
<td>1–3 mio.</td>
<td>6</td>
<td></td>
<td>60E2</td>
<td></td>
</tr>
<tr>
<td>&lt;1 mio.</td>
<td>7</td>
<td></td>
<td>46E1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sleepers</th>
<th>Ballast</th>
<th>Subsoil</th>
<th>Drainage</th>
</tr>
</thead>
<tbody>
<tr>
<td>wooden</td>
<td>good</td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td>concrete</td>
<td>medium</td>
<td>poor</td>
<td>poor</td>
</tr>
<tr>
<td>steel</td>
<td>poor</td>
<td>new line</td>
<td></td>
</tr>
<tr>
<td>bridge sleepers</td>
<td>—</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>others</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>concrete USP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>slab track</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>concrete HDS USP</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1.
Parameters and parameter values.
2.2 Working cycles: Input data

In the next step, it is necessary to attach the average maintenance regime to the Standard Elements. This is done by depicting the frequency of different maintenance works between one re-investment and the next one. As this should be done based on existing data, some aspects need to be considered, which are discussed below.

It might be that

- the existing maintenance is not the optimal one guaranteeing the economic service life.
- different maintenance regimes are executed in different regions of the network.
- maintenance regimes use slow orders to stretch maintenance cycles.
- financial or resource restrictions lead to the execution of different maintenance works.

Besides different aspects evaluations of the set of Standard Elements may cover, it can be stated that one Standard Element (set of parameter values) can have different working cycles (maintenance regimes).

The process followed in the latter is based on the idea to depict a sustainable maintenance regime, so neither includes speed restrictions nor insufficient maintenance.

The most challenging task is forming the working cycles for different parameter sets. This is true for depicting the necessary maintenance frequency as well as for the service life. The latter can be approached by using track records. In most cases, infrastructure managers store the “year of track relaying” as status data in their data warehouses. In assessing track age parameter-set-wise, we come up with a survival analysis showing reached service lives so far. This works in case of evenly distributed track ages and/or parameter sets already used longer than one service life (e.g., wooden sleepers). It fails, if parameter sets are relatively new (e.g., new track components or higher transport volumes) as we only see the first part of the service life in the survival analysis. Alternatively (or additionally), we can analyze the reached service lives of tracks at the point in time of relaying. Doing statistics on these data also leads to robust values while delivering the deviations from the mean in addition. Figure 3 shows such a frequency distribution analysis as an ex post evaluation for wooden sleepers. In this figure, 0 is no deviation from the depicted average service life, all values to the right stand for longer service lives, and all values to the left for shorter ones. Figure 3 shows additionally the La Place distribution in blue that fits sufficiently good for wooden sleepers.

Generally, maintenance demand increases with increasing track age. When using maintenance records, we thus need to consider track age as an important variable. Taking sections with similar parameters from all over the network, we have executed maintenance frequencies for different time frames in the service live. Averaging these frequencies leads to a first approach of the working cycles. As maintenance is
executed based on on-site track quality, these frequencies of course vary from section to section. Depending on the number of sections available, the averages of those frequencies might be more or less robust. Therefore, a consolidation process is necessary. This process is based on the experience of the track engineers. There are some rough plausibility checks that can be executed quite straightforwardly: Does maintenance increase over the service life? Does higher transport volume lead to tighter maintenance frequencies? Does poorer subsoil condition show intensified maintenance? With the knowledge and experience of the trained maintenance staff, we can derive consolidated maintenance frequencies.

In the end, the depicted maintenance frequencies in the working cycles need to deliver the executed maintenance amount of the analyzed network. The same is true for service lives: in calculating the average service life for all existing parameter sets and applying this to the total lengths of tracks, we can easily calculate the average amount of track renewal. If calculated values deviate from the existing maintenance and renewal works, the working cycles need to be adopted in an iterative way. Adding the unit costs for the single maintenance tasks, this plausibility check can also be executed for maintenance budgets.

3. Results

We collected maintenance frequencies for different technical boundary conditions from various infrastructure managers, mainly from Europe facing comparable mixed traffic networks. In this results section, we depict the main effects of changing parameter values on the maintenance frequencies and service lives. Concluding, we also calculated the average maintenance needs for an artificial network to underline these differences.

3.1 Ballast-related maintenance and renewal

As mentioned in Chapter 2, ballast maintenance frequency and service life of track cannot be analyzed separately, at least for tracks on concrete sleepers.
We start with the influence of track loading depicted in gross-tons. Note again that tonnage is only a rough estimate for the actual loading of track, but in this case, we compare mixed traffic tracks only so that the influence of different traffic segments and vehicles smooth out or average over the network. This is true for traffic volumes up to some 25 million gross-tons. Higher tonnages in mixed traffic can only be operated with an increasing amount of freight trains. This effect cannot be depicted by tonnage only [23]. If we look at the main maintenance action for the ballast, leveling-lining-tamping, we can see an almost linear increase in tamping needs, while service life drops also more or less linearly (Figure 4).

The curvature defines both tamping demand and service life to a certain degree, especially if curves get narrow. Below some 600 m, tamping demand increases slightly and service life starts to drop. In very narrow curves, about one-third of the service life is lost even though tamping is more than doubled (Figure 5). The high cant in combination with increasing lateral forces leads to a fast loss of track geometry.

The influence of substructure quality is dominant as Figure 6 shows: poor dewatering of the track leads to a one-third higher tamping demand, and poor soil (and proper drainage) to a doubled demand. With this increased ballast maintenance at least, the service life can be assured. If poor soil condition and poor drainage condition meet, service life can drop to half even though tamping is frequent (every

![Figure 4](image_url)

**Figure 4.**
*Leveling-lining-tamping over loading.*

![Figure 5](image_url)

**Figure 5.**
*Leveling-lining-tamping over track radius.*
third year) and ballast is to be cleaned one time. These technical consequences lead to the high economic efficiency of subsoil rehabilitation in such cases as the additional costs in track renewal are compensated by the saving in maintenance over the (prolonged) life cycle.

In ballasted track, of course, ballast quality is crucial. This is true for the composition of the ballast in terms of ballast stone size distribution (sieve curve) as well as the shaping of the single stones. The main trigger is the material quality though. This quality is assessed using the LA values usually (see Chapter 2). In case of magmatic material (e.g., basalt) with LA values below 14, the ballast is not the limiting component in track with loadings below 15 million gross-tons (mixed traffic) as also tamping demand is very low (every 10 years). Metamorphic material (LA values around 17, e.g., granite) leads to an acceptable tamping frequency (every 6 years for 10–15 mio. Gross-tons, Figure 7) and a reasonable service life. Poor ballast material (e.g., limestone) leads to doubled tamping needs on the one hand, while the halved service life compared to good ballast quality can only be achieved in cleaning the ballast once in the lifetime of track.

Moreover, the sleeper type in use triggers the tamping demand. Here, concrete and wooden sleeper perform similarly concerning track geometry stability (the service life of the wooden sleeper track is limited due to the limited average lifespan of wooden
sleepers, Figure 8). A remarkable reduction of tamping needs is recorded using concrete sleepers with under sleeper pads (USP): for the traffic load used in the example in Figure 8, the tamping frequency drops from every 6 years to every 12 years. As the sleeper-ballast interface provides much more contact area, stresses are lower and the ballast is protected especially at the uppermost layer, leading to a significant increase in service life.

3.2 Rail-related maintenance

This subchapter depicts the maintenance necessary for rails. Accumulated tonnage may lead to a necessary exchange of the rails due to an overridden fatigue limit. This limit is about 280 mio. Gross-tons for 49 kg rails, around 500 mio. Gross-tons for 54 kg rails, and beyond 1000 mio. Tons for profiles with more than 60 kg per meter. For the rail profile 60E1 or UIC60 which is widely used in European mixed traffic railway networks, a rail exchange due to this limit is not necessary generally looking at the achievable service lives (Figures 4–8) of 50 years in maximum. Even if the loading reaches some 100,000 gross-tons, which is somehow the maximum possible traffic volume in mixed traffic, rail replacement as a result of exceeding the fatigue limit will not be necessary.

What keeps is maintenance linked to rail surface failures and to the side wear in the outer rails of curves where the contact between wheel flange and rail head leads to heavy wear. While the latter phenomenon can only be handled by changing the rails, surface failures can be treated by rail grinding or milling as long as executed early enough. In sharp curves, corrugation waves and re-profiling are the dominant aspects, while in wider curves rolling contact fatigue (RCF) damage in form of head checks is the trigger for the rail surface maintenance. Figure 9 shows the number of grinding interventions for different track radii.

Rail grinding cannot be handled without looking in parallel to the rail exchange. Figure 10 gives the amount of outer rail exchange for different track radii. In brackets, we added the exchange of the inner rail which is a consequence of rail grinding due to corrugation waves on the one hand and on the other one of achieving matching rail profiles for outer and inner rail supporting smooth track guidance.

Both rail grinding and rail exchange can be reduced significantly by using higher rail steel grades. Figures 11 and 12 show the rail maintenance frequency over the trach

Figure 8.
Leveling-lining-tamping over sleeper type.
radius for different rail steel grades. As rails with higher steel grades come along with slightly higher investment costs only, the savings in maintenance pay back at least for high transport volumes generally.
3.3 Network-wide maintenance and renewal demand

Having described the average maintenance frequencies and the service lives as a consequence of varying boundary conditions, we can also calculate network-wide demands on this basis. This is important to guarantee sufficient budgets in order to achieve sustainable network quality and the economic optimum. The positive influence of higher-quality track components and improved subsoil can also be depicted on this aggregated level. Of course, in a network, it takes time until all track sections are equipped with the most sustainable components, but at least such evaluations can highlight the goal and support the implementation.

The following evaluations are performed for an artificial mixed traffic network of 10,000 kilometers. The network consists of 76 percent of straight tracks ($R > 1000$ m), 12.5 percent of $600 \text{ m} < R < 1000$ m sections, 6.5 percent of tracks with radii between 400 and 600 meters, 4.5 percent of radii in the $250 \text{ m} < R < 400$ m class, and 0.5 percent sharp curves below 250 meters. The track loading is fixed to 10 to 15 million gross-tons per year, summing up to $125 \times 10^6$ gross-ton kilometers per year. In the basic scenario, the tracks consist of concrete sleepers with 60E1 rails with standard steel grade R260 on medium ballast and good subsoil and good drainage conditions.

This configuration leads, according to the referring Standard Elements, to a maintenance demand of 1747 km of tamping, 504 km of rail grinding, 5.6 km of rail exchange, and a renewal demand of 283 km which is equivalent to an average service life of 35.3 years.

If we look at the ballast-related maintenance and the renewal demand for different ballast and sleeper types, and varying subsoil and drainage conditions, we can see the high importance of high-quality components (Table 2): perfect ballast helps reducing the tamping demand by 40 percent and renewal demand by 30 percent, while poor ballast in contrary leads to a more the double tamping demand, additional ballast cleaning needs and nevertheless to a 50 percent increased renewal demand. Moving from standard concrete sleepers to padded sleepers helps to achieve similar benefits than good ballast quality, almost 30 percent reduction of yearly renewals, and only half of the tamping demand.

The condition of subsoil and drainage is crucial. Facing poor dewatering conditions can easily increase the tamping demand by one-third, poor subsoil even by 100

Figure 12.
Rail exchange over track radius for different steel grades.
percent, and additionally costly ballast cleaning. Having both poor subsoil and poor drainage means doubled tamping demand (and some 2 percent of the network yearly ballast cleaned) and a doubled renewal demand. In this case and considering the transport volume, one-third of the network needs to be tamped every year and 5.7 percent of the track require track renewal.

For rail maintenance, the rail steel grade is a game changer: For the given loading of 10 to 15 mio. Gross-tons and a superstructure with concrete sleepers on medium ballast with good subsoil and drainage condition, rail grinding demand can be reduced by up to 40 percent using heat treated rails. The side wear-driven rail exchange (including the necessary exchange of the inner rail every second to third exchange) drops to 20 percent in the case of rails R350HT, to almost 0 in the case of a steel grade of R400HT (Table 3).

In extended mixed traffic networks, we find a mixture of these parameter values and tracks with different ages. Some—low—percentages of the networks might face any poor subsoil conditions. Ballast might be better or worse in different parts of the network or in different lines. We find different rail profiles, rail steel grades, and sleeper types. If assessing realistic samples of existing networks, it turns out that following a high-quality strategy has the potential of a 50 percent reduction of yearly maintenance expenses and up to one-third of renewal costs per year. Of course, the first step is to invest in more robust components and improved subsoil. This comes

### Table 2.
*Maintenance and renewal demand for different track structures.*

<table>
<thead>
<tr>
<th>Track structure</th>
<th>Tamping [km]</th>
<th>Ballast cleaning [km]</th>
<th>Renewal [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>concrete sleeper</td>
<td>medium ballast</td>
<td>1.747</td>
<td>0</td>
</tr>
<tr>
<td>concrete sleeper</td>
<td>poor ballast</td>
<td>4.494</td>
<td>169</td>
</tr>
<tr>
<td>concrete sleeper</td>
<td>good ballast</td>
<td>1.049</td>
<td>0</td>
</tr>
<tr>
<td>concrete sleeper</td>
<td>medium ballast</td>
<td>1.747</td>
<td>0</td>
</tr>
<tr>
<td>concrete sleeper</td>
<td>concrete USP sleeper</td>
<td>860</td>
<td>0</td>
</tr>
<tr>
<td>concrete sleeper</td>
<td>good subsoil</td>
<td>1.747</td>
<td>0</td>
</tr>
<tr>
<td>concrete sleeper</td>
<td>good subsoil</td>
<td>2.331</td>
<td>0</td>
</tr>
<tr>
<td>concrete sleeper</td>
<td>poor subsoil</td>
<td>3.479</td>
<td>100</td>
</tr>
<tr>
<td>concrete sleeper</td>
<td>poor subsoil</td>
<td>3.479</td>
<td>198</td>
</tr>
</tbody>
</table>

### Table 3.
*Rail maintenance for different rail steel-grades.*

<table>
<thead>
<tr>
<th>Rails</th>
<th>Rail Grinding [km]</th>
<th>Rail Exchange [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>60E1-R260</td>
<td>504</td>
<td>5.6</td>
</tr>
<tr>
<td>60E1-R350HT</td>
<td>407</td>
<td>1.2</td>
</tr>
<tr>
<td>60E1-R400HT</td>
<td>299</td>
<td>&lt;0.1</td>
</tr>
</tbody>
</table>
not for free but pays back in the long term. Economic evaluation is not the topic of this paper but is well-published [24, 25].

As shown, the Standard Element Approach allows for predicting future demand of track work, maintenance as well as track renewal. The following examples show the net wide effects of implementing innovation. The calculation is executed on a fictive network. Different innovative track components prolonging the service life are modeled. Furthermore, an increase in the transport volume of annual 2.5 percent is assumed. Starting at Figure 13, we see the forecast of track renewal assuming that transport volume is constant and tracks are re-built with the same components and on unchanged subsoil condition. The five renewal waves (in different colors in Figure 13) smooth out over the long term to a somewhat constant renewal demand.

If following the strategy to re-invest tracks always with the optimal component mix and to rehab subsoil in case it is necessary, the renewal demand decreases after the first renewal wave. The prolongation of service lives (e.g., due to padded concrete sleepers plus 25 percent [26, 27] stretches the necessary renewals in the future (Figure 14).

Considering an increase in transport volume, in this example by 2.5 percent per year, track sections move from one loading class to the next higher one. This goes...
along with decreasing service life and early renewal of course. Again, this process impacts the renewal demand in the long term only (Figure 15), but we see that it shifts the necessary track re-investments to the level displayed in Figure 13. We learn that further improving track components in order to increase the total service life of the track is not only to reduce maintenance in the short and mid term but to keep networks with growing transport volume in a balanced state.

This example underlines that Standard Elements form sound knowledge which can be used for various analyses and evaluations.

4. Conclusions

The methodology of Standard Elements is suitable for all infrastructure assets. Deriving deterministic maintenance cycles is only possible for assets with a wear-driven and thus loading-driven behavior (track, switches, bridges, catenary), in case of stochastic failure-driven assets (signaling) the working cycles depict probabilistic maintenance frequencies.

The Standard Element Approach is implemented at several railway infrastructure companies. Austrian Federal Railways, Swiss Railways [28], Scandinavian infrastructure companies, and railway companies in the Balkans, and in the Caucasus area. It always is the first step for implementing sustainable track asset management. In the past, the methodology led to new regulations for track components, specified for the different sets of parameters and thus a specific use (e.g., rail steel grades).

While the first implementations were primarily based on experience, progressive digitization, and more data in longer time series, allow for further specification and detailing of the Standard Elements. Working cycles can nowadays increasingly be based on deterioration functions derived from trend analyses of time-sequenced data. It should be noted that the basic thrust has not been lost by further detailing and that fine-tuning based on prognoses of track behavior is already taking place.

Essential specifications and extensions of the methodology are currently on the way. Thanks to new data, it is now possible to consider also the track work quality. In addition, more specific transport data is available allowing for considering wheel-rail interaction and also optimization within the parameter transport volume [23]. In addition, the model is currently being expanded to include environmental aspects.
CO₂ equivalents are calculated for track components, track work, and the end-of-life scenario and considered in the economic evaluation [29–31].

All these developments are possible due to additional and more specific data enabling more detailed working cycles. An adaption of the principles of the methodology of Standard Elements itself is not necessary.

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