WORLD BANK GROUP

UKRAINE: UKRZALIZNYTSIA (UZ) MODERNIZATION STRATEGY

Policy Note 5: Infrastructure Asset Management

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Acknowledgments

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Preface

This Policy Note is one of a series of individual papers originating in a request from Ukraine's Ministry of Infrastructure (MoI) and JSC Ukrzaliznytsia (UZ) to the World Bank to address specific topics concerning Ukraine's railway sector. The Policy Notes address the following topics.

1. **Railway market opening for cargo services:** progress in the meeting rail commitments in the EU-Ukraine Association Agreement, reorganization of UZ, Ukraine's readiness for and implications of market opening, pre-requisites to avoid leaving UZ in an unfavorable situation.
2. **Loss-making long-distance passenger services:** service costing, institutional and financial options for providing sustainable transport passenger services for long distance travel.
3. **Selected Cargo Business Issues**: specific matters on which Bank advice has been sought including cargo tariffs, customer service and perceptions, and operating efficiency.
4. **Debt management**: options for UZ to restructure its debt and reach a financially stable situation.
5. **Infrastructure asset management and prioritization of investment.** Asset management strategy and life-cycle costing in the renewal and reconstruction of UZ's railway infrastructure network.

This Policy Note is for **Topic 5: Infrastructure asset management and prioritization of investment.** It describes the methodology, data requirements and next steps for implementation of an asset management system that could identify necessary maintenance and renewal budgets in order to guarantee a sustainable railway infrastructure, measure the backlogs, identify optimum track technologies for individual parts of the network and assist decision-making in individual investment projects.

Acronyms

CURRENCY EQUIVALENTS

Exchange Rate (Feb 2019)

Currency Unit: Ukrainian Hryvnia (UAH)

USD 1 = UAH 26.9

ACRONYMS

AMS	Asset Management System
CAPEX	Capital Expenditure
FFU	Fibre reinforced Foamed Urethan
HDS	Heavy Duty Sleeper
IM	Railway Infrastructure Manager
LCC	Life Cycle Costing
NPV	Net present Value
OBB	Austrian National Railways
OPEX	Operating Expenditure
SBB	Swiss National Railways
TU Graz	Transport University Graz
UZ	Joint Stock Company, JSC Ukrzaliznytsia
USP	Under Sleeper Pad

Summary of Findings and Recommendations

This Policy Note describes the methodology, data requirements and next steps for implementation of an asset management system that could identify necessary maintenance and renewal budgets in order to guarantee a sustainable railway infrastructure, measure the backlogs, identify optimum track technologies for individual parts of the network and assist decision-making in individual investment projects.

The Ukrainian network covers some 27,000 track-km, (excluding stations, sidings etc). In the absence of detailed data yet available to the consultant, the amount of rehabilitated tracks of 2296.8 km in the last 5 years implies an average yearly renewal rate of some 450 km. This is little more than 1.5 percent of the network, implying that average service life would need to be around 60 years. Service life depends on the loading, on the many technical boundary conditions already addressed in this report, and on the maintenance regime applied. However, it is clear that an average of 60 years' service life is most unlikely to be attainable with today's track components and the amount of rail traffic in the Ukraine.

Implementation of a life cycle based asset management system is a challenging task for the infrastructure managers. Based on international experiences, it takes at least 1½ years, to reach the level necessary for strategic decision making based on an asset management system. This time schedule needs an active working group inside UZ meeting at least every six weeks. Starting the work requires an initial two-day seminar on the main principles for describing track behaviour using the Standard Element approach in order to ensure commitment of all working-group participants.

The first milestone of the working group is a set of Standard Elements describing the present situation and its history of maintenance and service lives of track in the Ukrainian railway network. The second milestone is a set of alternative technical scenarios enabling the definition of a sustainable solution. Reaching this second milestone, the renewal demand as well as the maintenance demand for a sustainable network can be calculated.

1. Economic evaluation of infrastructure – Track life cycle cost methodology

Life cycle cost of track identifies ballasted track component/element choices based on commonly used components, as well as alternative solutions covering innovations. The strategic life cycle analysis is based on attaining a more favourable CAPEX-OPEX balance (i.e. leading to lower life-cycle operational cost profiles without excessive initial CAPEX increases) as opposed to a more usual choice of components based on the minimization of CAPEX only. Designing such a methodology requires that the specifics of railway infrastructure be taken into account:

(a) The infrastructure of railways is very costly.

(b) The service life of infrastructure assets is very long, 30 years and often more. Consequently, all costs over the entire service life must be taken into account. This leads to the need for life cycle costing.

(c) Infrastructure is a precondition for train operating companies to earn revenues. However, these revenues cannot be directly linked to a specific type of track or track-work. Thus an economic evaluation of infrastructure can compare costs of different options only.

Life cycle costing in infrastructure (LCC) is a process whereby costs of various track alternatives are compared in order to identify the most sustainable and economical solution. On the cost side 'key ready' costs are used, a concept that includes trackwork costs, all logistic costs (e.g. transport of track materials), overhead costs, and also due to the long service lives, the cost of capital (interest rate). Downstream costs for train operators (costs of operational hindrances), due to track work or poor track quality, need to be taken into account. These costs occur at points of construction, maintenance and renewal. The scrap value or disposal cost for the previous asset is taken into account. All these costs are assembled for every alternative based on the working cycles of the Standard Elements. Standard Elements deliver a time sequence of costs from one re-investment to the next and are discussed in more detail below).

There are different methodologies available for an economic evaluation (Figure 1.1).

Figure 1.1 Methodologies for economic evaluations

STATIC	DYNAMIC
comparison of costs	net present value costs
comparison of profit	net present value
average profit	annuity[1]
productivity	internal rate of return
repayment period	repayment period

[1] annuity: annual average dynamic costs

Static methods of evaluation are inadequate because within long service lives, the cost of capital must be allowed for. Comparing the profit and the net present value cannot be used as there are no direct revenues. This is also true for the internal rate of return and the pay-back period. Thus the method to calculate the annuity (= dynamic average annual costs) remains as the appropriate method for comparing different superstructure options, as this method takes costs of capital into account.

Furthermore, it can be used for comparing alternatives with different service lives, as the total costs are converted to the average annual costs.

To calculate the annuity the user discounts the nominal values of all payments from their year of payment to the year 0 – that means over the time t in years – representing the present value (net value) using a discounting rate i

$$net\ value = nominal\ value * (1+i)^{-t}$$

Then all net values can be summed up resulting in the net present value.

$$NPV = \sum net\ values$$

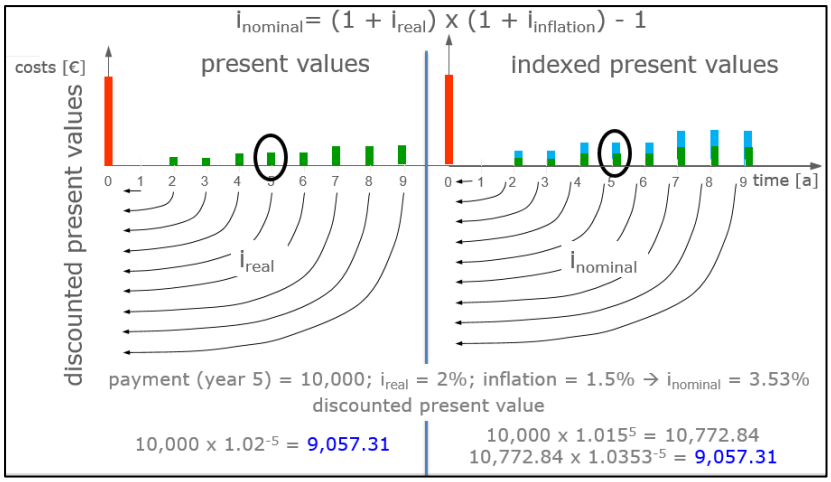
As the service lives of the alternatives to be compared differ, the decision cannot be taken on net present values. Multiplying the net present value with the capitalising factor (CF) results in the average annual dynamic costs, also named annuities.

$$CF = \frac{(1+i)^t * i}{(1+i)^t - 1}$$

$$A = CF * NPV$$

These annuities are proper for comparing alternatives with different investments, different maintenance costs and different service lives. It is proposed to use as discounting rate the real cost of capital without inflation. Inflation does not change the results and thus does not give any further information for decision making within infrastructure. However, inflation is not known for the coming 30 or more years. In figure 1.2 it is demonstrated that using the real discounting rate without inflation (left-side) delivers the same result as on the right-side implementing inflation. On the left side the payment (example a payment in the year 5) is discounted by the real cost of money. On the right side the payment is first increased with the inflation. Then the value including inflation is discounted with the nominal discount index which includes both the real cost of money and inflation. Therefore the results do not differ.

Figure 1.2 Calculating with or without inflation



As both calculations deliver the same results, either methodology can be used. However, taking inflation into account requires speculative assumptions about future inflation, though any inflation rate could be used without changing the result.

Independently from the two possible calculations, a high real discount rate would counteract the idea of evaluating sustainability by taking all cost over service life into account, by substantially devaluing future payments (Table 1.1).

Table 1.1 Effects of different discounting rates

years/rate	0%	1%	2%	3%	5%	10%	15%
5	100%	95%	91%	86%	78%	62%	50%
10	100%	91%	82%	74%	61%	39%	25%
15	100%	86%	74%	64%	48%	24%	12%
25	100%	78%	61%	48%	30%	9%	3%
30	100%	74%	55%	41%	23%	6%	2%

Table 1.1 shows the effects of different discounting rates. Discounting a payment from the year 30 to the year zero using an annual discount rate of 10 percent would devaluate the payment to just 6 percent of its nominal value. Therefore, using a high discount rate greatly downplays the significance of long-term effects. Application of LCC techniques provides management with an improved awareness of the factors that drive cost.

Costs will change over time. It is difficult to predict the total life cycle cost of long-lasting assets because of the high likelihood that there will be unexpected changes related to, for example, component costs and maintenance productivity. Therefore, the central LCC values that result from a study are not necessarily sufficient for decision-making. Sensitivity analyses must form an integral part of the economic evaluation. The best information can be gained by varying the individual input data separately, to identify the most relevant input data. The calculation will be executed using the same methodology as the primary one. So the annuities of the different alternatives are calculated, just one data set which is seen to be uncertain, is varied. This will be done until all uncertain data are varied. This sensitivity analyses will deliver different life cycle costs. However, the life cycle cost given in their annuities are not the relevant result of life cycle costing! Life cycle costing is used to identify the most economical solution. Thus the ranking of the alternatives is the relevant result. Within the sensitivity

analyses the stability of the ranking is checked. If the ranking is stable, it can be stated that the alternative ranking first will be the best solution without knowing exactly the costs which will occur due to this alternative in the next decades, but all other alternatives will involve higher costs.

In some cases, the methodology of calculating critical values can be helpful. In this case it is calculated how much a data set must differ, until the first and the second alternative will show the same economic efficiency.

Experiences show that in most cases the ranking remains stable. If a certain data set changes, for example it is assumed the labour costs increasing more than material costs, this is not depending on a single alternative, as it is not caused by the alternative. So it will happen to all alternatives. However, if the sensitivity analyses show a frequent change of ranking number one and ranking number two, it must be stated that from today's point of view these alternatives have most likely the same economic efficiency. As already mentioned, such results are unusual.

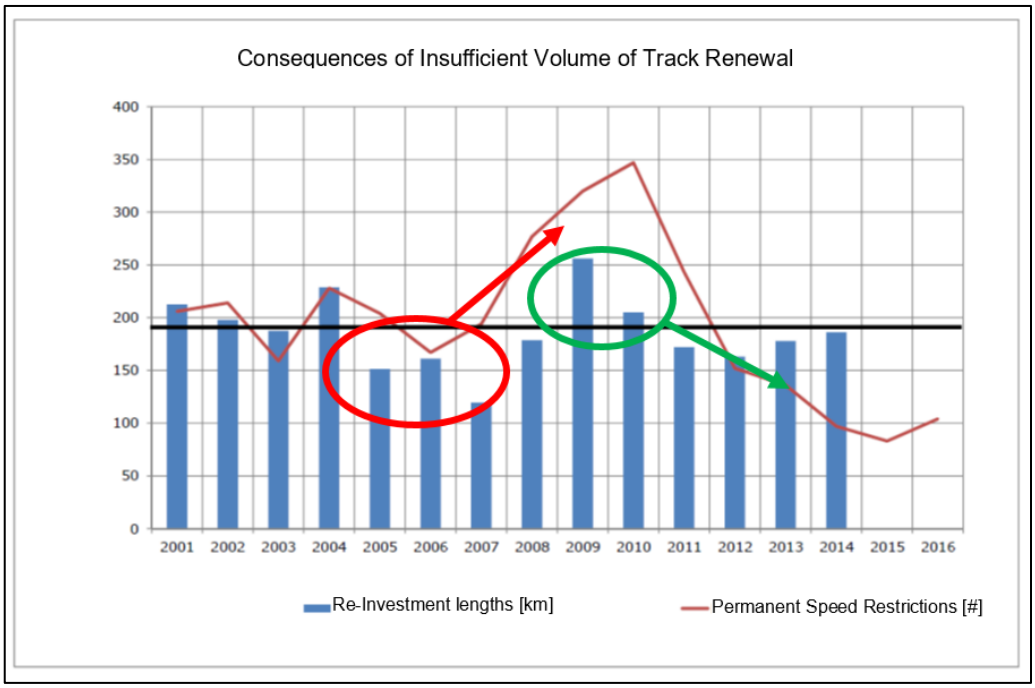
2. Examples for different loaded lines – 'Standard Element' approach

The Standard Element approach aims at describing track behaviour over its entire service life, so service life must be identified as well as the maintenance demand. However, "the track" or "the turnout" do not exist as unique technologies as different track/turnouts behave differently. So the superstructure must be analysed in detail. Furthermore, the condition of sub-soil and the dewatering system also have a strong influence on superstructure behaviour. Consequently, these conditions must also be taken into account.

The 'permanent way' of railways shows some specific characteristics. Two of these attributes make life cycle costing of railway infrastructure especially important: an extremely long service life and a strong relation between (initial) quality, maintenance demand and service life. Research into track behaviour shows that investment determines the initial track quality but does not automatically deliver service life. Maintenance transposes the potential for a service life given by the quality created by the investment into service life. It can be mathematically proven that the ratio of the maintenance intervals is indirectly proportional to the deterioration rates. This means that a halved deterioration rate leads to a doubled interval for maintenance actions and points to the importance of the rate of deterioration. Furthermore, the research indicates that increasing maintenance cycles due to high quality leads to a remarkable increase of service life. However, if the maintenance level is reduced leading to poor quality, service life will be shortened. These effects illustrate the overwhelming importance of track quality, namely the initial quality and the deterioration rate, for service life, maintenance demand and thus life cycle cost of track. So investment in quality and maintenance must be considered together. Focusing on just investment strategies or maintenance regimes in isolation will lead to sub-optimal decisions. In a nutshell: it's all about quality: quality in investment and quality maintenance in order to deliver sustainable and economical infrastructure.

This also means that track and turnouts have a long service life but only with sufficient maintenance. Even when quality maintenance is disregarded the technical reaction is not immediate. The reaction comes three to five years later and then maintenance becomes very expensive, if the problem still can be solved with maintenance (Figure 2.1). Neglect of quality maintenance often leads to the result that the problem can eventually only be solved by track renewal. Another possibility is to reduce the load and the quality demand. However, in a first step the static load cannot be reduced as this would mean a reduction of the transport volume. But the dynamic load can be reduced, as it is speed dependent. Therefore, permanent speed restrictions reduce the requirements for track, in its load carrying capacity and quality demand. If reduced budgets still do not allow a proper maintenance, even the axle load must be reduced. However, in this case transport volume is directly affected. In the case of rotten wooden sleepers even safety becomes an issue, as gauge and twist may exceed the acceptable limits.

Figure 2.1 Number of Permanent Speed Restrictions versus Track Renewal



In Figure 2.1 the horizontal dark line presents the strategic renewal demand, the blue bars show the executed renewal and the brown graph depicts the number of permanent speed restrictions. Some years after insufficient renewal the number of speed restrictions increases (red). Increasing the renewal volume, some years later the number of speed restrictions decreases again (green).

Though general track behaviour follows some rather simple principles, analysing the status of a given track is complicated, as track behaviour is very sensitive to many boundary conditions, including:

(a) Subsoil quality
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 needs least maintenance and delivers maximum service life.

(b) Existence and quality of the dewatering system
A good subsoil will stay good only if a properly installed and a maintained dewater system exists.

(c) Traffic load and type of traffic (speed, axle load)
The transport load triggers maintenance need: the more and heavier the trains operated, the higher the maintenance demand and the shorter service life.

(d) Ballast Quality
Ballast is the most relevant component of track superstructure and its quality crucial.

(e) Track Alignment (mainly the radii)
The alignment of track is a major aspect of track maintenance demand. A curved track needs a separate maintenance regime or simply more maintenance than a straight track section. Consequently, service life is shorter in curved track compared to a straight one.

(f) Type of Superstructure (type of sleeper, rail profile and steel grade, status of rail pads and fasteners)

All track components influence track behaviour. The rail profile defines the service life of rail in terms of fatigue resistance. Higher profiles are able to carry more gross tonnes before frequent rail breakages occur. The rail steel grade influences the wear resistance and the resistance against rail surface failures (mainly cracks).
The sleeper type has a major impact on the load distribution towards the ballast bed: wooden sleepers deliver a slightly more elastic track and thus distribute the load on more sleepers. The main difference to concrete sleepers occurs on the sleeper-ballast-interface as ballast stones can penetrate the sleeper surface and generate a bigger load carrying area in this way. Concrete sleepers on the other hand are cheaper (influencing the investment cost of track) and reach longer service lives as they are not subject to natural wear.

Additionally, for turnouts the following parameters need to be take into consideration:

(g) Geometry of turnout
Maintenance demand of turnouts is influenced to a high degree by their geometry, meaning turnouts in straight sections, turnouts in curved sections without cant, turnouts in curved section with cant.

(h) Diverging radius
The influence of diverging radii depends on the diverging speed. This is true except for the wear of the switch rail. However, the length of a turnout is defined by its diverging radius and thus the costs of investment and maintenance depend on this parameter.

(i) Type of frog
The frog can either be fixed or movable, resulting in different investment costs and different maintenance demand. Furthermore, different materials are in use. Nowadays manganese frogs are a standard solution.

(j) Transport load
The transport load of diverging trains influences maintenance demand and service life of switch rails.

Table 2.2 shows as example the parameters that are taken into account in Austria for defining general strategies for open track.

Table 2.2 Parameters for Describing Open Track

transport volume [gross-tonnes/day, track]	track [number]	rail profile [ ]	rail steel grade [ ]	sleeper [ ]	radius [m]	rails [ ]	subsoil condition [ ]
> 70,000	1	60E1	R400HT	concrete	> 3,000 m	CWT	good
45,000 - 70,000	2	54E2	R350HT	concrete USP	1,000 m - 3,000 m	jointed	weak
30,000 - 45,000	2+2	49E1	R260	wooden	600 - 1,000 m		poor
15,000 - 30,000			R200		400 m - 600 m		bad
8,000 - 15,000					250 m - 400 m		
2,000 - 8,000					< 250 m		
< 2,000							

Speed is not shown in Table 2.2 because in Austria, speed and transport load go hand-in-hand. If this is not the case, speed forms an individual parameter.

In order to describe track behaviour, the Institute of Railway Engineering and Transport Economy developed the methodology of Standard Elements. One Standard Element thereby describes track behaviour for one specific set of the parameters mentioned above. These Standard Elements were set up for various infrastructure companies in Europe, based on data warehouses (recording car data, maintenance data and operational data) and the experience of railway staff.

For the parameters concerning superstructure, the values are simply the components to be used, e.g. wooden sleepers or concrete sleepers. Values for the parameter subsoil are more problematic as technical descriptions are usually not available. Therefore, the subsoil indices are defined qualitatively based on the consequences of different subsoil to the superstructure.

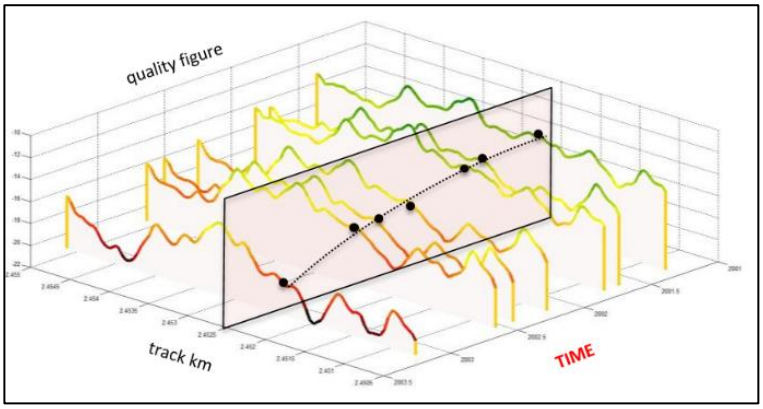
Traffic Load and Alignment need clustering of discrete values. The topic of alignment of track deals with radii in track.

The “number of tracks” parameter with its values “single-tracked” and “double-tracked” is not decisive for most types of track behaviour, but influences trackwork costs due to different logistics (e.g. materials transport) and track closure times, which has operational cost consequences.

Describing track quality behaviour, various boundary conditions such as transport volume, type of superstructure, quality and status of all components, alignment (radii), ballast quality, quality of sub-layer as well as sub-soil, the functioning of the dewatering system, position of stations, bridges and turnouts must be taken into account. Therefore, a data-warehouse was set up covering track recording car data (initial status, present status, and quality figures), type and age of superstructure and sub-structure, and transport load. The research was based on these data for the main railway network of Austrian Federal Railways covering time sequences of already 17 years (Figure 2.2).

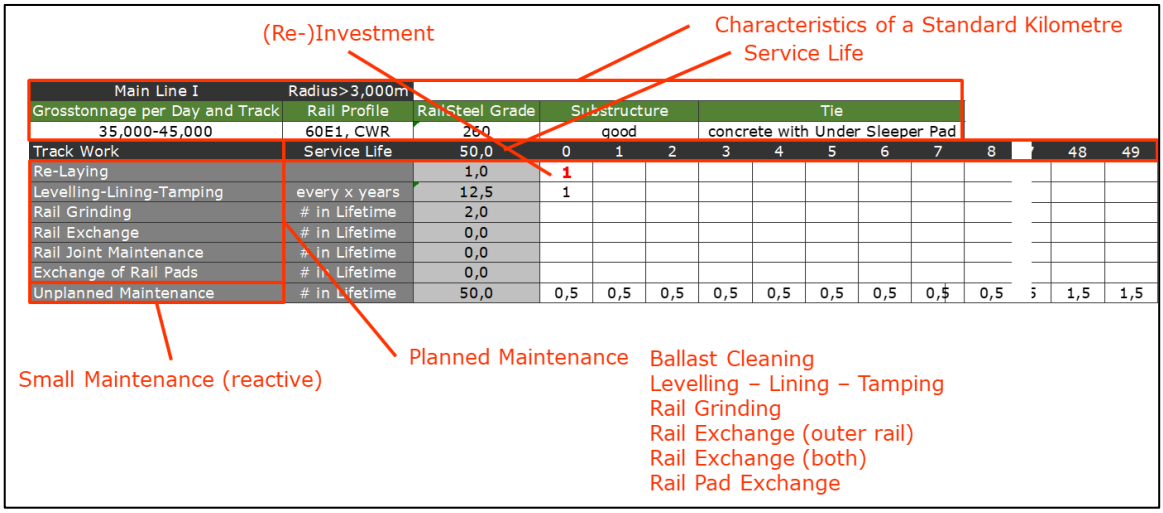
This structure allows comparison of different types of superstructure for a large number of sections facing the same boundary conditions. The comparisons can be done every 5 metres for a data set of 4,500 km in total and thus provides a large number of comparable sections. This allows identification of the effects of initial quality as well as calculation of the specific deterioration rate for a given set of boundary conditions and different types of superstructure.

Figure 2.2: Analyses of Track Behaviour over Time



The core information of every Standard Element is given in a table called "working cycle" (Figure 4.2), presenting service life and maintenance demand of track.

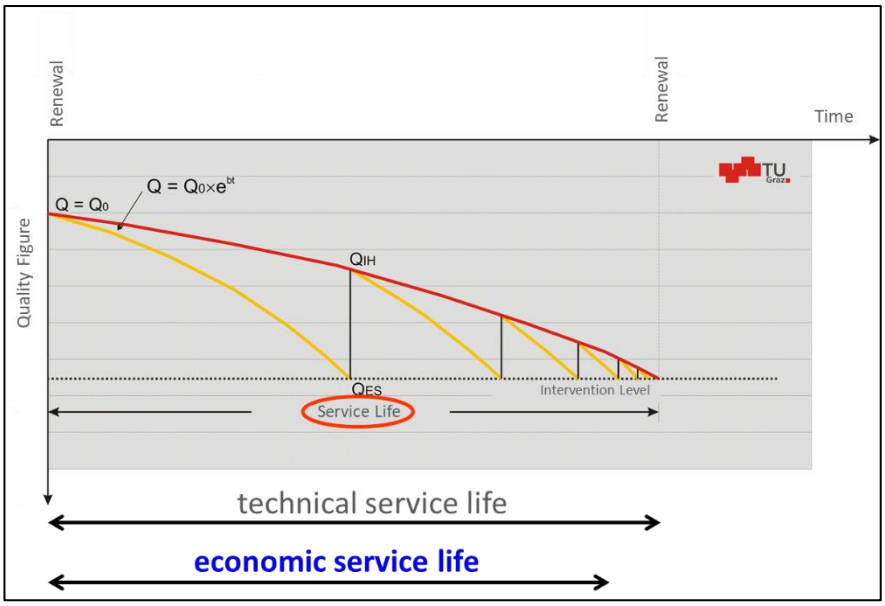
Figure 2.3 Working Cycle of a Standard Element



Main Line I	Radius>3,000m													
Grosstonnage per Day and Track	Rail Profile	Rail Steel Grade	Substructure			Tie								
35,000-45,000	60E1, CWR	260	good			concrete with Under Sleeper Pad								
Track Work	Service Life	50,0	0	1	2	3	4	5	6	7	8	48	49	
Re-Laying		1,0	1											
Levelling-Lining-Tamping	every x years	12,5	1											
Rail Grinding	# in Lifetime	2,0												
Rail Exchange	# in Lifetime	0,0												
Rail Joint Maintenance	# in Lifetime	0,0												
Exchange of Rail Pads	# in Lifetime	0,0												
Unplanned Maintenance	# in Lifetime	50,0	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	1,5	1,5	

As the decision whether track or turnout renewal is necessary must be based on the calculation of the economic service life the difference of technical one. This is pictured in Figure 2.4.

Figure 2.4 Technical versus Economic Service Life



In Figure 2.4, track quality behaviour over time is presented. Starting from a certain quality level and depending on track renewal technologies, track deterioration starts (yellow line). As track faces dynamic loading the behaviour follows an e-function. When an intervention level is reached, a maintenance action is executed in order to bring the quality back to an acceptable level (black vertical line). However, the initial quality cannot be reached as there is wear and tear due to operation. Then

deterioration starts again. At a certain point of time the quality level after maintenance remains poor – technical service life is reached. However, it is not economic to invest that much into maintaining an old track so the economic service life must be shorter. If the cost saving by reducing the depreciation due to prolongation of service life is lower than the necessary additional maintenance cost, the economic service life is reached. Therefore, in principle the definition of the economic service life is rather simple, as is economic efficient to prolong service life as long as the decrease in depreciation is bigger than the increase of maintenance necessary for the service life prolongation:

$$\frac{d\ depreciation}{dt} = \frac{d\ maintenance}{dt}$$

The depreciation can be calculated very easily being a function of investment divided by service life. Estimating the maintenance demand of the coming years is challenging, as it requires a prediction based on time sequences of data describing track quality behaviour. Keep in mind, all service lives given in the standard elements are based on these considerations and thus describe the economic service lives. That means, these service lives can be overwritten either by restricting the traffic (axle load restrictions or speed restrictions) or executing dense maintenance – but it will never be economic.

The number of possible combinations or Standard Elements therefore is high for an entire network (may be more than 10,000), but not realistic. Some combinations are not allowed due to regulation, some are technically not feasible, and – the highest number – are simple not existing due to technical knowledge and understanding. For a specific line the number of relevant Standard Elements is even more limited.

Figure 2.5 presents two examples for Standard Elements of two different sets of boundary conditions. The first working cycle describes track on standard gauge with a light rail continuously welded mounted on concrete sleepers in a radii between 600 m and 1200 m, with good subsoil, proper dewatering system and a good ballast facing a traffic load of 8 to 12 million gross-tonnes per year. The second working cycle describes a similar situation, all parameters are the same, but the traffic load is just between one and three million gross-tonnes per year.

Figure 2.5 Relevance of Traffic Load for Service Life

	R>1000	double track																															
GBT/year,track	rail profil/sleeper/rail	steel grade	sleeper pad			ballast			subsoil																								
10.000.000	49E1concreteCWR	260	no			normal			good																								
maintenance work	life span	28,0	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27			
renewal	times/life span	1,0	1																														
levelling-lining-tamping	times/life span	14,0		1			1			1		1		1		1		1		1		1		1		1		1	1	1			
spare part exchange	times/life span	1,0																		1													
rail grinding	times/life span	1,0		1																													
rail exchange	times/life span	0,0																															
sleeper exchange	times/life span	0,0																															
ballast cleaning	times/life span	1,0																1															
subsoil rehabilitation	times/life span	0,0																															
restressing CWR	times/life span	1,0																1															
joint maintenance	times/life span	0,0																															
rail pad exchange	times/life span	1,0																		1													
spot repair	times/life span	28,0	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	1	1	1	1	1	1	1	1	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5			

	R>1000	double track																																											
GBT/year,track	rail profil/sleeper/rail	steel grade	sleeper pad			ballast			subsoil																																				
2.000.000	49E1concreteCWR	260	no			normal			good																																				
maintenance work	life span	38,0	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37					
renewal	times/life span	1,0	1																																										
levelling-lining-tamping	times/life span	7,0		1						1						1						1						1					1					1							
spare part exchange	times/life span	0,5																				0,5																							
rail grinding	times/life span	1,0		1																																									
rail exchange	times/life span	0,0																																											
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rail pad exchange	times/life span	0,0																																											
spot repair	times/life span	37,0	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5						

Technical evaluation of track must identify its economic service life and thus take track quality behaviour over time into account. Therefore, the Standard Elements form a sound base for describing the condition of track, allowing estimation of track work necessary, either renewal or maintenance.

TU Graz holds a large set of Standard Elements covering many different parameter values for track and turnouts. There is a wide range of

- different transport loads (from 2,000 gross-tons per day and track up to 100,000 gross-tons per day and track),
- different radii (from radii smaller than 250 m up to straight sections), and
- various subsoil qualities (good sub-soil, sub-soil affected by poor dewatering of track, soft-soil, and soft-soil with poor dewatering).

These parameters are covered by existing and proven sets of Standard Elements. Regarding types of superstructure Standard Elements for track, including the following components, are available:

Asphalt Layer

Standard Elements for track with and without asphalt layer below ballast allow evaluating the effects of asphalt layers. The Standard Elements are based on several test sections in Austria.

Ballast (LA value < 17 up to LA > 25)

In comparing different track behaviour using different qualities of ballast from different countries (Austria, Switzerland, Norway, Germany, Croatia) the effects of a wide range of ballast qualities is described in several Standard Elements.

Sleepers (concrete, concrete with sleeper pads (USP), wooden, steel, HDS, Frame Sleeper, FFU)

In Austria and Switzerland concrete sleepers and wooden sleepers are in use. SBB also uses steel sleepers. In the last years much research was carried out for new, innovative sleeper types. These sleepers differ in material, form, and equipment. In Austria, concrete sleepers with USP are already the standard solution and thus in wide use, HDS, Frame Sleepers, and FFU has been tested. Thus Standard Elements for these various sleepers are available.

Rail Profile (60E1, 54E1, 54E2, 49E1, 46E1)

The rail profile influences the demand for levelling-lining-tamping, the service life of rails due to different wear reserves, and fatigue. Due to a full set of Standard Elements in Austria, Switzerland, and Croatia the rail profiles can be compared by existing Standard Elements.

Rail Steel Grade (R260, R350HT, R400HT)

The rail steel grade defines the wear resistance, relevant in small curves, and has a big influence on RCF, relevant in curves. Test results in Austria and Germany allowed incorporation of these effects into specific Standard Elements.

If any boundary condition, such as another gauge or a specific type of component, is not covered by the existing Standard Elements there are tools to adjust the Standard Element towards these situations as well, for example the Swiss Wear Factor, which was developed in close cooperation with SBB. This allows incorporation of, for example, speed ranges up to 250 km/h and axle loads of more than 22.5 tonnes.

As Standard Elements have been elaborated, life cycle cost can easily be calculated in replacing the workload in the cycles by the costs of the work. Standard Elements can be adopted for different countries by adjusting them according to the specific parameter sets relevant in the specific country. Therefore, the methodology has general applicability, for different infrastructure components as well as for describing different railway networks. However, the costs of trackwork differ widely between different technical options and can also differ remarkably from one country to another. An economic calculation based on the adopted Standard Elements must be calculated for the given price levels in each different country.

3 Identification of technical backlog in investment and maintenance

Identifying the technical backlog in infrastructure investment and maintenance can be done in two different ways:

i. Based on the Standard Element approach, the Standard Elements for the entire network (see also next chapter) form an average service life (depending on the amount of the different elements). This provides a basis for calculating an average necessary renewal rate by simply dividing network-length by this average service life. This rough estimate can be compared to the average annual renewals. If the actual is lower, especially over a long period, this means a constant, ongoing over-aging of the network.

ii. The second option – that should be at least partly adopted – is to identify sections that are over-aged. Over-aged track faces either operational restrictions (speed restrictions and/or reduced axle-loads) or needs intensive, costly maintenance in order to technically enable the delaying of track renewal.

The first alternative is proposed for Ukraine as it allows for a fast overview of the track age distribution of the network. That includes not only identifying the backlog, but also the challenges of maintenance, and renewal needs in the upcoming years.

The Ukrainian network covers some 27,000 track-km, (excluding stations, sidings etc). In the absence of detailed data yet available to the consultant, the amount of rehabilitated tracks of 2296.8 km in the last 5 years implies an average yearly renewal rate of some 450 km. This is little more than 1.5 percent of the network, implying that average service life would need to be around 60 years. Service life depends on the loading, on the many technical boundary conditions already addressed in this report, and on the maintenance regime applied. However, it is clear that an average of 60 years' service life is most unlikely to be attainable with today's track components and the amount of rail traffic in the Ukraine.

The high-loaded section analysed by the consultants (some 240,000 gross-tonnes/day on each track) would imply a service life of about 15 years under Austrian conditions (sustainable maintenance assumed). The lower loaded section analysed (Odesa-Sort. – Chornomorska) that has some 50,000 gross-tonnes/day on each track, might have 40 years of service life, again with application of sustainable maintenance. However, the data provided indicate that these service lives might not be reached due to much lower maintenance levels actually executed. Time-series data are short, but maintenance data indicate that the estimated service lives based on international experience seem to be feasible.

The estimation has also been carried out for the sub-set of lines having transport loads of at least 10,000 gross-tonnes per day, this give some 18,000 track-kilometres. Assuming the renewals of the last 5 years have been mostly allocated to these lines, their average service life is estimated to be about 40 years. That seems still to be too high and indicates there is a backlog, but not a severely over-aged main network. Conversely, that means the rest of the network, the low and very low loaded lines, must be already under operational pressure and is heavily over-aged. This needs to be taken into account in any future appraisal of what to do with low density lines (See Policy Note 1, Annex A). These assumptions are meanwhile confirmed by UZ:

i. The currently used ranking principle of UZ consists of two steps: Projects are ranked according to gross-tonnes-kilometre on the section and further prioritised depending on the relevance

for long-distance passenger trains on the main destinations (Odessa – Kiev, Charkiw – Kiev, and Lviv – Kiev). Having an asset management system as proposed would help prevent exceeding the economic service life and avoid (further) reductions of operating speed on the main passenger lines.

ii. A first estimation on service lives based on the given data for two lines carrying different traffic loads show that an average 40 years on higher loaded lines cannot be realised presently due to a lack of comprehensive maintenance. For very high loaded sections (88 mio. gt/year, track, figure 3.1) 15 years could be possible, but would require systematic levelling-lining-tamping. For medium loaded lines (20 mio. gt/year, track, figure 3.2) data show some 30 years of service life possible without major maintenance. This figure can be increased to 40 years if proper maintenance would be executed. This first technical evaluation underlines a backlog of re-investment which is currently increasing.

Figure 3.1 preliminary Standard Element UZ (88 mio. Gt/year, track, straight track, heavy superstructure, good subsoil and dewatering system)

Line	Alignment			No of Tracks			Service Life								
Standard Element (modified)	straight			double-tracked			15								
Traffic Load	Sleepers			Rails			Subsoil		Ballast						
240.000	concrete			60E1			good		Granite						
Track Work	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Renewal	1														
Levelling-Lining-Tamping	1		1		1		1		1		1	1	1	1	1
Spot Tamping					1						1				
Rail Grinding															
Rail Exchange															
Sleeper Exchange															
Ballast Cleaning															
Small Maintenance	0,5	0,5	0,5	0,5	0,5	1	1	1	1	1	1,5	1,5	1,5	1,5	1,5

Line	Alignment			No of Tracks			Service Life				
Znamenka - Korystivka, 312 пк 1 - 318 пк 8	straight			double-tracked			11				
Traffic Load	Sleepers			Rails			Subsoil		Ballast		
239.452	concrete			P65			good		Granite		
Track Work	0	1	2	3	4	5	6	7	8	9	10
Rehabilitation/Reconstruction/Major repair of the track	1										
Medium Repair									0,056		
Complex-Sanitary Repair									0,056		

Line	Alignment			No of Tracks			Service Life	
Znamenka - Korystivka, 312 пк 1 - 318 пк 8	straight			double-tracked			28	
Traffic Load	Sleepers			Rails			Subsoil	Ballast
239.452	concrete			P65			good	Granite
Track Work	2011	2012	2013	2014	2015	2016	2017	2018
Rehabilitation/Reconstruction/Major repair of the track	1							
Medium Repair								
Complex-Sanitary Repair								

Line	Alignment			No of Tracks			Service Life
Znamenka - Korystivka, 318 пк 9 - 320 пк 2	straight			double-tracked			28
Traffic Load	Sleepers			Rails			Subsoil	Ballast
239.452	concrete			P65			good	Granite
Track Work	2013	2014	2015	2016	2017	2018		
Rehabilitation/Reconstruction/Major repair of the track	1							
Medium Repair								
Complex-Sanitary Repair								

Line	Alignment			No of Tracks			Service Life
Znamenka - Korystivka, 320 пк 3 - 321 пк 2	straight			double-tracked			28
Traffic Load	Sleepers			Rails			Subsoil	Ballast
239.452	concrete			P65			good	Granite
Track Work	2018							
Rehabilitation/Reconstruction/Major repair of the track	1							
Medium Repair								
Complex-Sanitary Repair								

Line	Alignment			No of Tracks			Service Life				
Znamenka - Korystivka, 321 пк 3 - 332 пк 10	straight			double-tracked			28				
Traffic Load	Sleepers			Rails			Subsoil		Ballast		
239.452	concrete			P65			good		Granite		
Track Work	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Rehabilitation/Reconstruction/Major repair of the track	1										
Medium Repair									0,056		
Complex-Sanitary Repair									0,056		

Figure 3.2 preliminary Standard Element UZ (20 mio. Gt/year, track, straight track, heavy superstructure, good subsoil and dewatering system)

Line	Alignment	No of Tracks	Service Life
Standard Element (modified)	straight	double-tracked	40

Traffic Load	Sleepers	Rails	Subsoil	Ballast
45.000 - 70.000	concrete	60E1	good	Granite

Track Work	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
Renewal	1																																							
Levelling-Lining-Tamping	1				1				1				1				1				1				1				1				1				1			
Spot Tamping													1												1															
Rail Grinding																																								
Rail Exchange																																								
Sleeper Exchange																																								
Ballast Cleaning																																								
Small Maintenance	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5

Line	Alignment	No of Tracks	Service Life
Odesa-Sort. - Chornomorska	straight	double-tracked	31

Traffic Load	Sleepers	Rails	Subsoil	Ballast
51.233	concrete	P65	good	Granite

Track Work	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Renewal-Levelling-Lining-Tamping-Spot Tamping	1																															
Rail Exchange																	1															
Sleeper Exchange																																
Complex Sanitary Repair																																1

Line	Alignment	No of Tracks	Service Life
Odesa-Sort. - Chornomorska, 1276 пк 1 - 1277 пк 7	straight	double-tracked	31

Traffic Load	Sleepers	Rails	Subsoil	Ballast
51.233	concrete	P65	good	Granite

Track Work	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Renewal-Levelling-Lining-Tamping-Spot Tamping	1																															
Rail Exchange																																
Sleeper Exchange																																
Complex Sanitary Repair																																1

Line	Alignment	No of Tracks	Service Life
Odesa-Sort. - Chornomorska, 1277 пк 8 - 1279 пк 1	straight	double-tracked	32

Traffic Load	Sleepers	Rails	Subsoil	Ballast
51.233	concrete	P65	good	Granite

Track Work	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Renewal-Levelling-Lining-Tamping-Spot Tamping	1																																
Rail Exchange																																	
Sleeper Exchange																																	
Complex Sanitary Repair																																	1

4. Steps required for implementation

Implementation of a life cycle based asset management system is a challenging task for the infrastructure managers. Due to international experiences, it takes at least 1½ years, to reach the level necessary for strategic decision making based on an asset management system. This time schedule needs an active working group inside UZ meeting at least every six weeks. Starting the work requires an initial two days seminar on the main principles of proper describing track behaviour using the Standard Element approach in order to ensure commitment of all working-group participants.

The first milestone of the working group is a set of Standard Elements describing the present situation and its history of maintenance and service lives of track in the Ukrainian railway network. These Standard Elements needs national and international verification as this forms the base line for all economical comparisons and thus for all derived strategies.

The second milestone is a set of alternative technical scenarios enabling the definition of a sustainable solution. This again is a task for the working group challenged with existing international experiences. Reaching this second milestone, the renewal demand as well as the maintenance demand for a sustainable network can be calculated. Comparing these figures with the existing situation (first milestone) allows identifying the current backlog and can form a base for budget discussions.

A seminar on the economic evaluation provides the possibility for the UZ to implement the Standard Element approach as a UZ decision tool for track asset management.

4.1 Data Requirements

To establish a comprehensive Life Cycle Management in which all decisions are taken that focus on a modern, sustainable railway system, requires further effort:

(a) A set of Standard Elements needs to cover at least 80 to 90 per cent of the network.

(b) The associated maintenance demands must be specified including small, reactive maintenance.

(c) Track costs must be calculated and documented on a uniform basis including costs of material, machinery, staff, and overhead costs.

(d) Speed restrictions (if existing) must be monetarised by an approach that is feasible for the existing data.

Point (a) needs a clustering of parameter-values and the identification of necessary parameter-sets to describe the Ukrainian network. The process to be followed is based on the idea to depict the existing situation, but not to include speed restrictions in the basic cycles as those are very likely triggered by local effects and thus hinder a comparison of different Standard Elements. Furthermore, plausibility checks (e.g. more traffic → more maintenance → shorter service life) might be impossible.

A major task is to form working cycles for the entire service life (see below). Especially the concept of the service life is a challenging one.

It is an option to analyse historic track data if it exists: in comparing track status, data documentation concerning the “year of track laying”, service life can be calculated. This is time-consuming and often not possible due to missing data as infrastructure managers sometimes simply overwrite old status data when renewing the track.

The other option is to analyse existing tracks in terms of a “survival analysis”. This works properly, if the parameter set has existed for more than a service life. The analysis would deliver the service life as the maximum of track age found for this set. This option is feasible for some Standard Elements only.

Having in mind the already mentioned implications, working cycles have to be formed for different sections of the network, fulfilling the parameter values of a Standard Element (Figure 4.1, NB: artificial network for illustration purpose only). Those sections are of different ages and thus show maintenance efforts of different time slices. Of course, this work is supported positively if the time-period of existing data is long.

It is important for the representativeness of the generated working cycle to merge data to avoid the risk of depicting only local variations.

Figure 4.1 Data for Working Cycles I

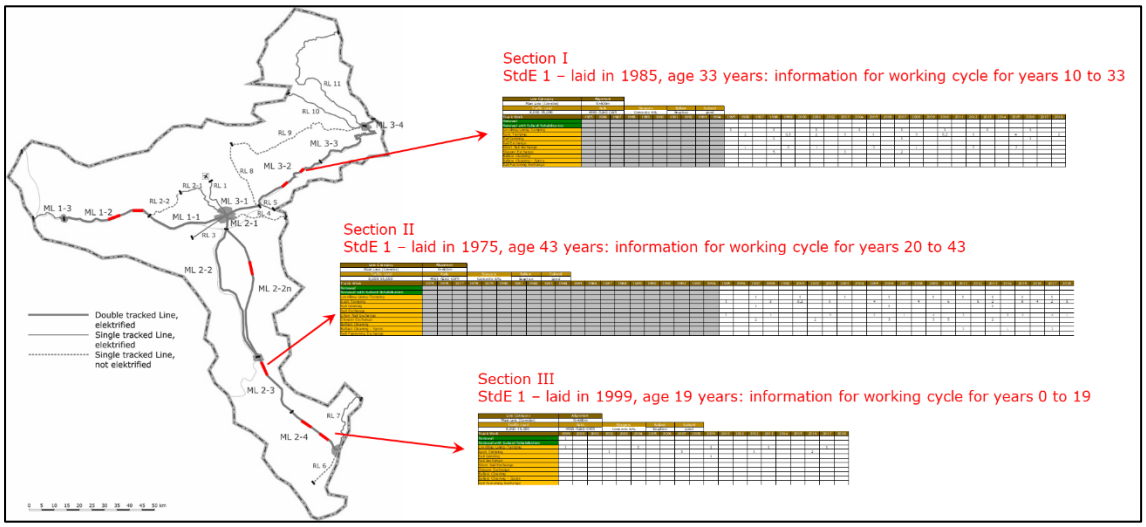
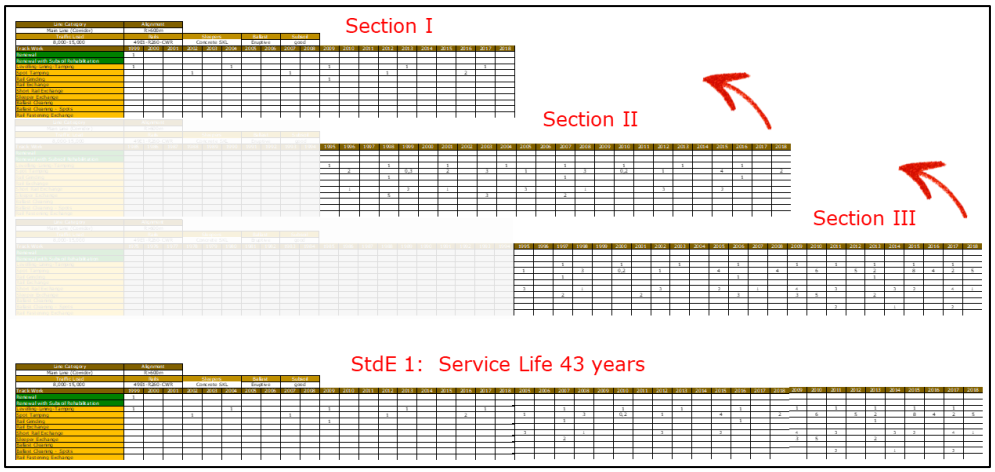
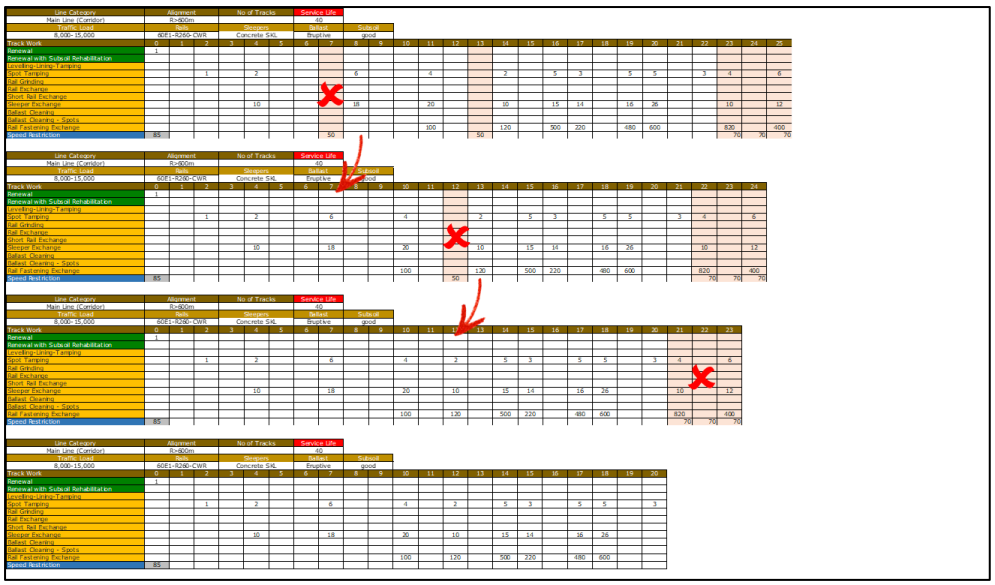


Figure 4.2 Data for Working Cycles I



Up to now no Standard Elements allow permanent speed restrictions due to a lack of quality. This is because speed restrictions (slow orders) are not cost-free maintenance actions. However, years of additional service life can be created. The economic impact of slow orders is discussed later on, but it can be stated that speed restrictions might be an opportunity for dedicated sections (with very low traffic volume and/or freight trains only). It is impossible to compare working cycles and service lives of cycles with and without speed restrictions. Therefore, it is necessary to eliminate slow orders from the existing data. This is done by shifting the maintenance cycles as showed in Figure 4.3. Years with slow orders at the end of service life are simple cut of the time-row.

Figure 4.3 Averaging Different Sections

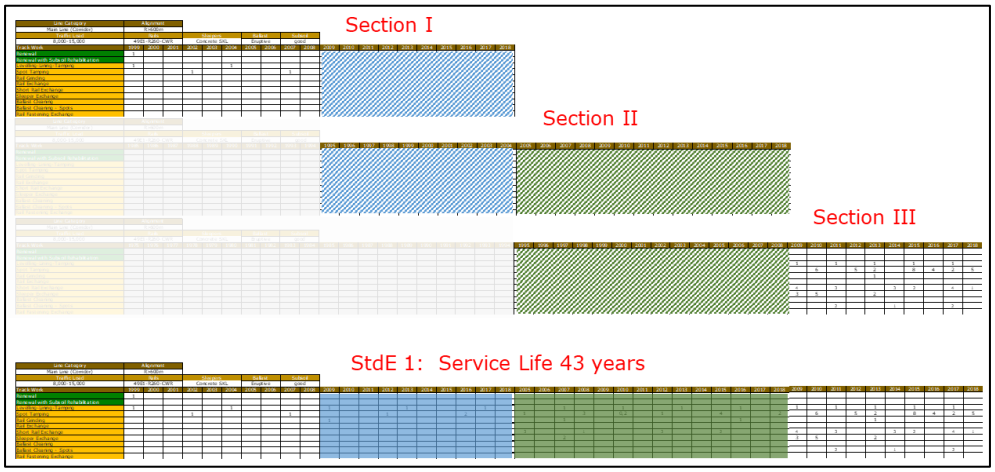


In the process of merging data, the averaging is of great importance. For the consecutive evaluations it is necessary to work with geometric mean values (putting more weight on data with a higher number of sampling points, in case of track longer length) as the mean maintenance regime multiplied by the total length of one Standard Element must sum up in the executed amount.

In this respect, it is important if average yearly values are displayed (e.g. 250 metres of 1 kilometre tamped every year or “0.25” in every cell) or if the cycle depicts a certain average frequency of a work

(e.g. 250 metres of 1 kilometre tamped every year or “1.00” every 4 years). In terms of costs, these two possibilities deliver nearly the same result.

Figure 4.4 Averaging Different Sections

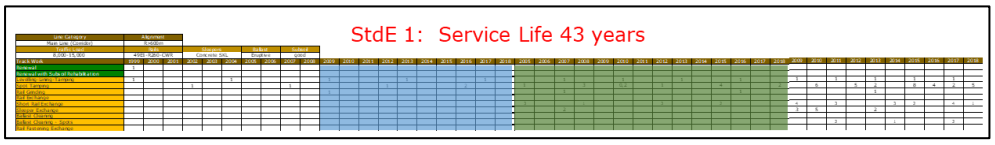


After running through these first three process steps, the resulting working cycle needs to be consolidated. The process includes averaging of various sections from different parts in the network, with different ages and different philosophies of maintenance, due to the human factor in local decision-making.

4.2 Strategy with or without permanent speed restrictions

Assuming a sustainable maintenance without strategic slow orders (see above), the wear-characteristic of track and its components asks for increasing maintenance towards end of service life. This effect should manifest of course also in the working cycles. It might be that in the transmission zones between the different coloured segments in the working cycle example in **Error! Reference s ource not found.** (white to blue, blue to green, and green to white), averaging could lead to skyrocketing and/or sharply dropping might occur. These effects are very likely not realistic and thus objective for a smoothening.

Figure 4.5 Averaging Different Sections



Especially, maintenance actions with long frequencies (e.g. rail exchange of outer rails in curves) must be treated carefully and accurately. If, for example, rail exchange was done in one section in the “blue” area of the cycle in Figure 4.5 and in the “green” area in another section, averaging is not the accurate approach, but shifting.

4. 3 Plausibility Check

Working cycles should always be cross-checked with expert knowledge before being used for further evaluations. Similarly, the plausibility of the working cycles in regard to each other must be checked. This process is crucial for the parameters “Transport Load” and “Subsoil” especially. Higher transport

loads should result in more maintenance demand, but this might not be evident due to possible different maintenance approaches in different regions. As long as the link to the service life is not dissolved, this fact is not crucial because evaluations might indicate that other maintenance frequencies are economic.

The negative consequences on track maintenance of poor subsoil, or poor drainage, are well documented: required maintenance of ballast bed (levelling-lining-tamping) increases. And, as ballast is the crucial element for track service life (most likely in case of concrete sleepers), service life decreases as well. The classification of the parameter "Subsoil" is not data-driven, but a kind of subjective rating based on the behaviour of the entire track done by the responsible track engineer. As this classification may be different in different parts of a network, its plausibility must be checked in a comparison of the respective working cycles.

4. 4 Cross check with international experiences

Various infrastructure managers have already examined the Standard Element approach and verified their working cycles and service lives by live and frequent matching of executed maintenance and track renewal. TU Graz could support this task. Using this experience, the parameter value linked maintenance frequencies and service lives can be challenged in considering similar boundary conditions. Especially the type of ballast must be taken into account robustly, as it is crucial for the entire behaviour of track.

If these challenges are addressed, the economic approach "Standard Elements" can support

(a) the identification of necessary maintenance and renewal budgets in order to guarantee a sustainable railway infrastructure ready to cope with future loadings – and thus also evaluate backlogs,

(b) the identification of components to be used for different parts and lines in the network, and

(c) if local data are added, decision making for single re-investment projects.

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