OPTIMISATION OF POINT LIFE CYCLE COSTS THROUGH LOAD-DEPENDENT MAINTENANCE

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ABSTRACT

An increasing traffic demand and competition between the traffic modes force the railway operators to improve their economical results. Thisou can be achieved primarily by reducing costs and by keeping a high standard in service and quality whereby an increase of attractiveness for potential customers can be realised. Especially the German Railways, while preparing itself for going public, demands for a higher relevance of the financial result.

Both infrastructure managers and railway operators have to consider that cost reducing actions are most effective when having a high impact on the life cycle costs (LCC) of the railway system and its components. Maintenance costs of railway infrastructure are such cost drivers. Track sections owned by the German Railways are categorised depending on their load per week for determining the time intervals of preventive maintenance of the infrastructure devices such as points. Unfortunately, there are only 3 categories. Such a rough classification is far from condition based maintenance and therefore includes optimisation potential. This paper summarises the results of simulation supported evaluations of cost savings which can be realized by a more load than time dependent maintenance of points. A track section north of Hanover, Germany owned by the German Railways is taken as an example to compare the current situation with an alternative point maintenance concept based on the recordings of the vehicle crossings. The study points out the possible reduction of scheduled inspections and shows cost savings under the premise of a constant system availability and safety.

The examinations underline the need for load-dependent maintenance of points as a step towards more cost-efficient preventive maintenance of railway infrastructure and therefore a decrease in whole-life costing (LCC).

KEYWORDS

Points, preventive maintenance, load-dependent maintenance, LCC

1. INTRODUCTION

The current development on the traffic market demands a more economical driven business strategy of the two railway operation parties, the infrastructure managers and the train operator companies. In a surrounding of increasing competition between the traffic modes and the governmental demand for a more market oriented behaviour the two parties are forced to improve their price-performance ratio. For being able to offer logistic and transportation services at attractive prices both of them have to cut costs without reducing the system's quality. But when considering different ways for cost reductions, the decision makers have to keep in mind that only the long-term effect defines whether the overall economical impact is positive or not. This aspect means for the cost perspective that not only the capital expenditures have to be considered but also the costs generated in later periods. For this reason Life Cycle Costs (LCC) as the sum over all costs generated in the life phases: development, production, service and disposal of a product or system (DIN EN 60300-3-3) should be used as an evaluation instrument.

For the infrastructure managers the maintenance costs are of special relevance since they take a big portion in the life cycle costs and are therefore identified as cost drivers. So when aiming for a better economic efficiency a reduction of maintenance costs has a high impact on the overall result. A reduction of point maintenance costs again has a high leverage effect on the maintenance costs as stated by the UIC study INFRACOST (Stalder, 2001). Because of their construction they have a relatively high liability to wearout.

Starting point for the idea of a simulative evaluation of a load-dependent maintenance concept as presented in this paper is a software link between the simulation software RailSys® and an in-house created Cost-Benefit Tool. The link between railway operation simulations and economic efficiency evaluations doesn't exist in this manner so far. This idea is discussed in the first part of the paper. An important issue thereby is the definition of economic efficiency.

Secondly the existing concepts for point maintenance practised by the German Railways are examined. How the presented idea for a load-dependent maintenance differs from the general concepts and what cost savings can be realised will be presented and substantiated by the simulation of an exemplary track section.

2. ECONOMIC EFFICIENCY EVALUATION THROUGH TOOL LINKING

2.1 Economic Efficiency

Economic Efficiency is defined as the relationship between costs and revenues created by a machine or a system. For investment projects economic efficiency means that its net present value (NPV) is higher than zero.(Gabler, 2000) The NPV is therefore a financial expression for the attractiveness of an investment seen over its entire investment period by considering expenses, revenues, the capital market and time (Perridon & Steiner, 2004). The NPV can be calculated for different purposes. NPV figures for the entire analysed track section (infrastructure, vehicles and operation) or for single track infrastructure elements etc. are calculable. The mathematical expression for the NPV is shown in (1). The revenues (R) and costs (C) per year and the chosen interest rate (q) over the regarded time period (n) are the input variables.

$$C_o = \sum_{t=0}^{n} (R_t - C_t) \bullet \frac{1}{q^t} . \qquad (1)$$

For the train sector, which is characterized by long economic life-times of the facilities, a lasting optimisation of the cost-benefit structure for the infrastructure managers and the train operator companies can only be achieved by a long-term view on costs and revenues. This means the consideration of all life phases (Fig. 1) of the system and its structure. The vertical line in Figure 1 represents the two perspectives existing in a product life cycle. While the formation cycle is primarily of interest for the product manufacturer, the market cycle determines the economic efficiency relevant for the product user. Hence in practice economic efficiency evaluations mostly never consider the whole life cycle but cost and revenue positions generated either in the formation cycle or in the market cycle.

When optimising maintenance strategy as it will be discussed in this paper the focus lies on the operation and maintenance phase.

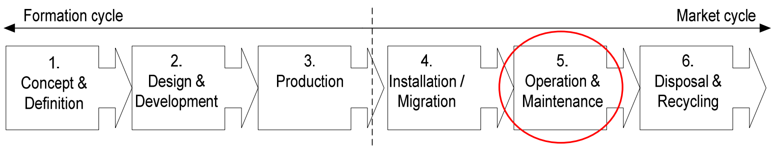

Figure 1: Product life cycle phases (DIN EN 60300-3-3)

For the cost perspective the use of the life cycle cost approach is necessary. As defined, life cycle costs are understood as the sum over all costs generated throughout the life cycle phases of a product (DIN EN 60300-3-3). Various cost components of track and rolling stock generated during the railway operation and their cause-effect chains have to be considered when setting up a Cost-Benefit Tool and defining the interfaces to the railway operation simulation software. The cost components which define the life cycle costs of a railway operation system are shown in Figure 2. Here the cost positions of the life cycle phases seen from a system user perspective (not customer) – installation/ migration, operation/ maintenance and disposal/ recycling – are captured in the cost pools purchase expenditure, utilisation costs and disposal costs. In addition there are overhead costs which cannot be attributed to one life cycle phase only. Such are costs generated by an information management system. The cost pools are subdivided into the corresponding cost elements. The cost elements in the cost pools are distinguished between being of recurring, varying amount (orange), recurring, constant amount (grey) or non-recurring amount (green).

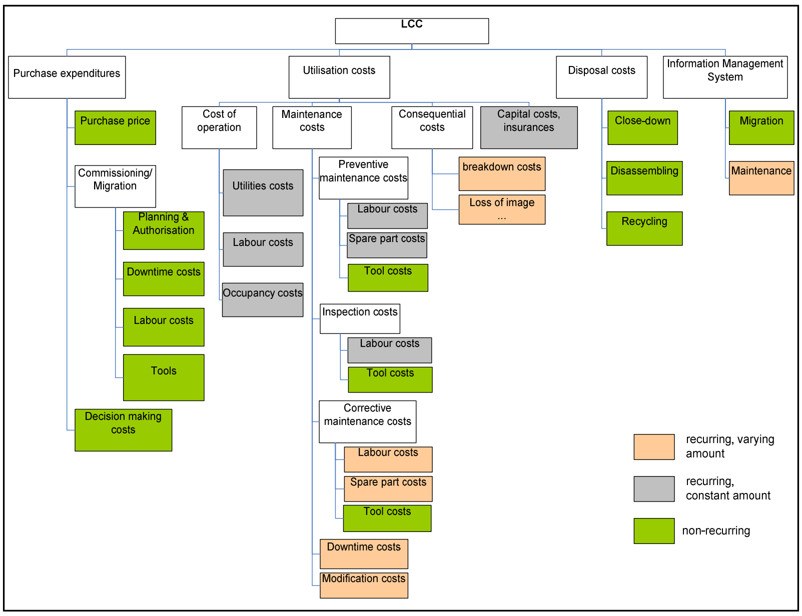

Figure 2: Life cycle cost components

On the benefit side there are at first the direct benefit factors. They are defined through the revenues out of ticket sales, track access charges, subsidies etc. and therefore comparatively easy to determine. In addition there are indirect revenues for example in the manner of non-occurred costs caused by a very good system availability etc. which have to be considered as well. The scientific question hereby is if there is the quantification of these aspects so they can just as well be entered into the cost-benefit figure.

2.2 The Link

The creation of a tool link has been necessary since tools for making long-term evaluations of the economic efficiency of different life cycle strategies for the railway sector as for example the choice of an operation procedure or a maintenance strategy are missing so far. Therefore the Institute of Transportation Systems started on looking for ways to give especially infrastructure managers a useful instrument for making decisions under consideration of both operative and economical aspects.

Helpful hereby can be railway operation simulations which not only consider operative aspects but also economical ones. While there exists several railway operation simulation software (e.g. RailSys®, Open-

Track®), it is yet not standard to reuse obtained simulation results for an economic evaluation of the considered and simulated scenarios. The Institute of Transportation Systems has therefore implemented a software link between the simulation software RailSys® and an in-house created Cost-Benefit Tool. With the latter the cost and revenue positions of the evaluated system with its chosen life cycle strategy can be calculated. New and of scientific and practical interest is therefore the idea of linking railway operation simulations to cost-benefit examinations. With the developed tool link economic efficiency evaluations for the railway sector can be now done in an efficient way.
The systematic approach of evaluating the simulated railway operation scenarios is shown in Figure 3.

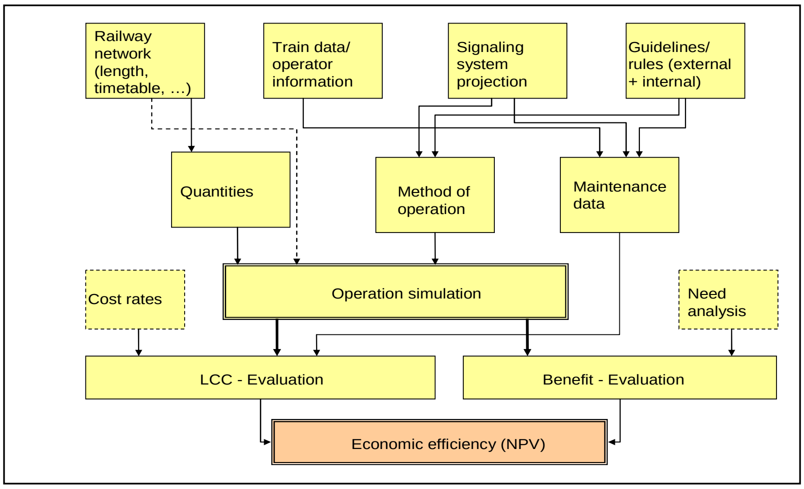

Figure 3: Systematic approach for tool linking

Above figure indicates the steps of how the economic efficiency evaluations are done with the use of the operation simulation software RailSys®. First of all the scenarios which want to be simulated have to be implemented in RailSys®. This means mapping the track topology, including the timetable and implementing the chosen signalling system projection. Railway network and the method of operation determine the track infrastructure elements and their quantity. Timetable and train information set up the time of operation. With this information the operation simulation can be done. The results of the operation simulation do influence the cost side (LCC) as well as the benefit side. Only dynamic figures, that means information dependant on the simulation run, can be obtained from the simulation, e.g. quantity figures, operation time, driven distance. Cost facts and static information, that means data which cannot be received through output files of the operation simulation software (e.g. maintenance intervals) are also needed. The user of the Cost-Benefit Tool has to fill in the additional information, which is detached from the simulation output files, via an entry mask. The interface between RailSys® and the Cost-Benefit Tool has been realised through Visual Basic for Applications (VBA).
This approach was the starting point for the idea of using timetable information for setting up a load-dependent maintenance concept.

3. PREVENTIVE MAINTENANCE CONCEPTS

As defined in EN 13306, preventive maintenance is carried out at predetermined intervals or according to prescribed criteria to reduce the probability of failure and therefore the number of corrective maintenance cases. Its intention is to slow down the reduction of the wearout stock (see also Figure 6). The wearout stock of an item is defined as the stock of fulfilling its functions which is realised through production, preventive maintenance and updating. (DIN 31051)
Generally speaking there are two ways of defining a preventive maintenance concept. The first is to do preventive maintenance on a fix schedule purely time dependent. The second concept is based on current product condition. Both concepts, as described in the following chapter, are implemented at the German Railways whereas the first concept is more common till this day. With the definition of the maintenance concept the number of maintenance work activities differs.

3.1 Status quo at German Railways

Fix preventive maintenance intervals

For tracks owned and maintained by the German Railways the enterprise guide line 892 is the most relevant one. Herein the intervals and kind of work are described separately for the existing track components. According to the relevant load of the track section there are three main categories which are used for the maintenance classification. Dependent on the result of the following equation (2), the track and therefore the track components are assigned to one of the three main existing load categories 28, 29 and 30.

$$\text{Load figure} = \text{Number of Trains} \bullet \text{Tonnes transported} \bullet 10^{-6} \text{ per week} \qquad (2)$$

It becomes obvious that the preventive maintenance for the components along the track section of the German Railways depends on the number and weight of the trains running. The assignment is accordant to Table 1**Fehler! Verweisquelle konnte nicht gefunden werden.** which is part of guideline 892 at the German Railways.

Load Category	Traffic volume	Load figure
30	low	0-35
28	normal	36-600
29	high	>600 or V_{max} > 160km/h or V_{max} = 160 km/h and NeiTech, and all equipment on IR/IC/ICE- track sections with an one hour cycle

Table 1: Load categories at the German Railways

Kommentar [BJ1]: Bezeichnungen immer unter Bild oder Tabelle schreiben – bitte konsequent im Paper!!!

In addition to the three main load categories there are minor categories for seasonal used tracks or for equipment which is no longer used but still stands in the field. Therefore, for tracks with regular traffic the three categories indicated in Table 1**Fehler! Verweisquelle konnte nicht gefunden werden.** are the relevant ones.
Accordant to the load category calculated for the regarded track there are fix preventive maintenance intervals. They and the work to do are prescribed in the German Railways internal guide line 892. Figure 4 shows an excerpt from this guide line relevant for the preventive maintenance of points.

1	2	3	4			5	6
Lfd. Nr.	Tätigkeiten		Instandhaltungsfristen (Monate) Meister LST | Bez L Modul 892.0103 Absatz:				Abnahme-/ Umbauprüfung
			28	29	30	40	
8	Gestängeabdeckung unbeschädigt? (Entfällt bei WA 350 auf Schwingenlagerung)		2	2	4		x
9	**Sind Antrieb und Lagerung fest miteinander verbunden, die Befestigung auf der Rippenplatte in Ordnung und Splinte vorhanden (außer bei Sechskantmutter mit Klemmteil)?** **[zusätzlich: 2 Monate nach Einbau überprüfen]**		**6**	**3**	**12**	**x**	**x**
	Bei WA 350: Bei DR Lager- und Übertragungsteilen prüfen der Punkte aus DA 10, Anlage 26, lfd. Nr. 2, Seite 125 bis 127		**6**	**6**	**6**	**x**	**x**
10	Fluchtet der Antrieb mit der Gleislage und der Schieberstange? Bei WA 350 : Prüfung des Antriebs auf waagerechte Lage bzw. leichte Neigung zur Weiche (Regenwasser auf Gestängeab-deckung, Stellschieber bzw. Prüfschieber darf nicht Richtung Antriebsgehäuse laufen)		6	6	12		x

Figure 4: Excerpt from German Railways guide line 892

Condition-based maintenance

Besides preventive maintenance based on fix intervals the German Railways also practises a condition-based maintenance concept for track devices by the use of sensor technology. With the sensors a constant monitoring of the condition of the supervised component is possible. So in this case the actual wearout of the components becomes relevant and is the indicator for the necessity of maintenance works or inspections. Of course, the condition-based maintenance also demands a higher flexibility in the maintenance organisation. The advantage of such diagnose systems lies in the reduction of the frequency of maintenance work and less preventive maintenance work since only the necessary units are maintained. Therefore the maintenance work has a higher efficiency. The disadvantage lies in the diagnosis system itself. It is an additional infrastructure element which has to be bought and also maintained itself and can also fail.
There is another approach of doing condition-based maintenance. This idea, which has been developed at the Institute for Transportation Systems, envisions that the wearout of railway infrastructure can be modelled as soon as the relevant impact factors influencing the wearout are known. Therefore it's essential to know the cause-effect chains. The implementation of an additional supervising system is hereby not necessary. This approach for a condition-based maintenance will not be described in detail in this paper. The intention of this paper is to describe the idea of a load dependent maintenance for points.

4. POINTS

Points are part of the railway infrastructure with whom a crossover from one track to another without interruption or stop of the vehicle is realised. (Berg & Henker, 1978) They therefore play an essential role in ensuring system flexibility.
Figure 5 shows the main parts of a point which are the blade device, the common crossing, the operating apparatus and the point periphery.

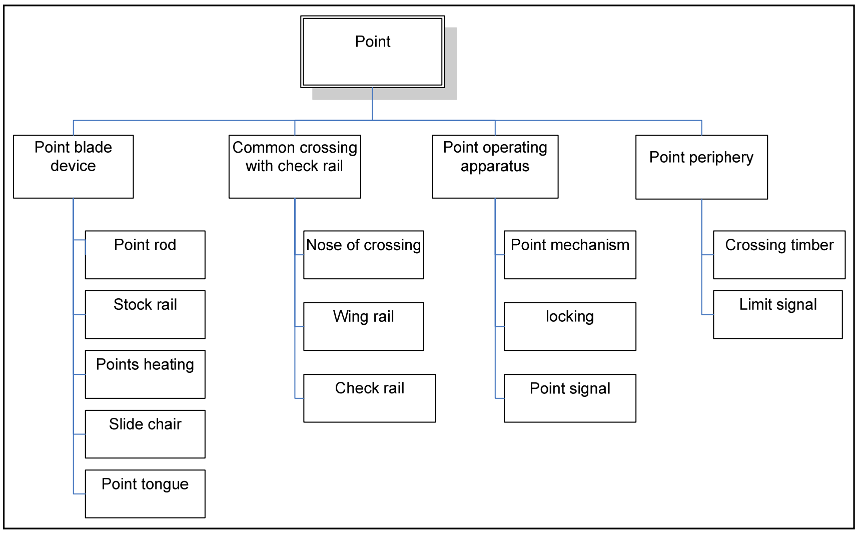

Figure 5: Point product structure

For the maintenance of points owned by the German Railways there are both ways – time and condition based maintenance – possible. Although in comparison to other European countries as e.g. the Netherlands (Herkes, 2007) the use of the more efficient condition-based maintenance is not as common in Germany because of missing maintenance flexibility. Instead the use of fix intervals determined by the load category (see (2)) is implemented. Concerning these fix time intervals for preventive maintenance there are two spots of bother. The first one is that these intervals for points have been set up in the past based only on experience in the field. There hasn't been any adjustment due to changes in the point technology in the last years. Secondly the wearout of points is highly load-dependent as described below. Because of this aspect the rough classification into three load categories relevant for all railway infrastructure components (see Table 1**Fehler! Verweisquelle konnte nicht gefunden werden.**) seems to contain point maintenance optimisation potential. How this can be exploited will be outlined in chapter 5.

The wearout of points is determined by lots of aspects as for example the point construction and material or the average traffic or track parameters (Zwanenburg, 2006). All these aspects have an influence on the wearout stock of each point. The qualitative devolution of a wearout stock of a point is shown in Figure 6. The wearout of points is caused by mechanical (interaction between point and vehicle), chemical (corrosion) and natural (climate, temperature) processes. (Berg & Henker, 1978)

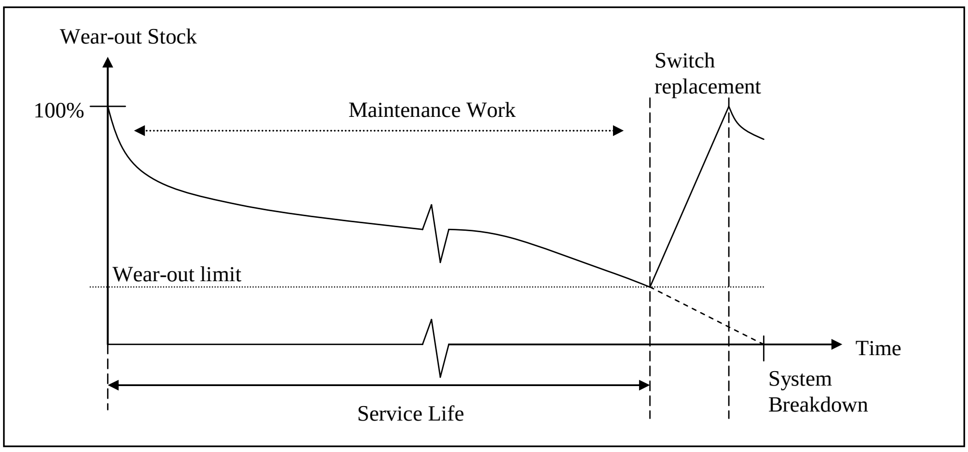

Figure 6: General devolution of the wearout stock of a point
(Schilling & Lücking, 2003) (DIN 31051)

All these aspects influencing the wearout of a point need to be considered when setting up the maintenance concept for points with its intention of realising a high component availability and reliability (for RAMS specifications see EN 50126). Hereby it is important that maintenance work prevents the wearout stock to fall below the wearout limit which is defined as the minimum level of wearout stock (see Figure 6). Beneath this limit the level of system safety, availability or reliability is too low and the system itself cannot be restored properly through maintenance work anymore. It cannot any longer be prevented from breakdown and a point replacement becomes necessary. So the knowledge of the devolution of the wearout stock is a precondition for the optimisation of the point maintenance concept. Therewith both aims – doing point maintenance more efficient and securing the same level of system availability – can be achieved. The circumstance that preventive maintenance of points is done on a basis of a trisection is the starting point of the idea to make point maintenance more cost-efficient with the use of railway simulations.

5. LOAD-DEPENDENT MAINTENANCE

5.1 Preliminary Considerations

Preventive Maintenance Costs

When trying to realise more cost-efficient point maintenance one needs to have an overview of the relevant cost positions and therefore of the composition of the overall preventive maintenance costs for one component. For preventive maintenance the following cost equation is valid (3).

$$C_{PM} = c_{PM} \times N_{PM} \tag{3}$$

$$c_{PM} = p_{WH} \times t_{PM} \times LN_{PM} + MC_{PM} \tag{4}$$

$$N_{PM} = f(f_{PM}) \tag{5}$$

C_{PM} - Overall Costs for Preventive Maintenance
c_{PM} - Costs for each Maintenance Case
N_{PM} - Number of Preventive Maintenance Cases
f_{PM} - Frequency of Preventive Maintenance Work

p_{WH} - Price per Working Hour
t_{PM} - Duration of Preventive Maintenance Work
LN_{PM} - Labour needed for each Maintenance Case
MC_{PM} - Material Costs; normally of small amount

As stated above in chapter 3 both the specific operation characteristics of a point (average load, construction etc.) and the chosen maintenance concept determine the frequency of preventive maintenance work and therefore the number of preventive maintenance cases. As shown in equation (3) the number of preventive maintenance cases N_{PM} strongly determines the overall preventive maintenance costs C_{PM}.

Object of Investigation and Boundary Conditions

The effect on the preventive maintenance costs is calculated for a single way track and an approximate traffic of 50 passenger trains per day. The trains have the same net weight since they are of the same kind. The chosen example is fairly simple but since the complexity of the example does not influence the presented idea or its feasibility this procedure is permitted. Based on equation (2) and with a net weight of the trains running of 500 tonnes the following load figure (LF) of 61.25 has been calculated for the chosen track section (6). This corresponds to the load category 28 which stands for normal traffic (see Table 1**Fehler! Verweisquelle konnte nicht gefunden werden.**).

$$\mathrm{LF} = (50 \times 7) \times (50 \times 500 \times 7) \times 10^{-6} = 61.25 \qquad (6)$$

For the evaluation of the effect on the preventive maintenance costs additional parameters have to be set up. As boundary conditions for the cost evaluation (the costs per working hour, number of staff needed per maintenance case and duration of each preventive maintenance case) (see equation (4)) figures based on the ones used at the German Railways have been used. Material costs have not been considered in the evaluations. The cost figures stay fix for the three evaluated maintenance scenarios in chapter 5.2. Therefore the difference in the three scenarios lies in the number of preventive maintenance cases. The preventive maintenance costs for the points at the chosen single way track have been evaluated for a period of 5 years. They are expressed in a Net Present Value figure calculated with a discount rate of 8 percent.

5.2 Simulative Evaluations and Maintenance Cost Saving Potentials

The information about the trains running as e.g. their weights has to be implemented in the railway operation simulation software RailSys®. They can then also be retrieved for maintenance evaluations.
The definition of the evaluated maintenance scenarios which have been evaluated against each other is based on the rough classification of track sections at the German Railways. As calculated in chapter 5.1 the chosen example belongs to the tracks of normal traffic. As indicated in Table 1**Fehler! Verweisquelle konnte nicht gefunden werden.** all tracks with a load factor between 36 and 600 (except high speed lines) belong to the same track category. Therefore the infrastructure elements along the track are maintained after the same intervals (see Figure 4). If we calculate backwards with equation (2) we see that if all trains have an approximate weight of 500 tonnes the overall number of trains (NT) running on the track and therefore causing the same maintenance intervals lies between 39 (7) and 158 (8) per day. Under the assumption of the same number of trains running every day a year this would make a minimum number of vehicle crossings of 39x365=14235 and a maximum number of 158x365=57670.

$$LF_{min} = 36 = (NT_{min} \times 7) \times (NT \times 500 \times 7) \times 10^{-6}$$
$$NT_{min}{}^{2} = \frac{36}{0.024} \quad (7)$$
$$NT_{min} = 38.7$$

$$LF_{max} = 600$$
$$NT_{max}{}^{2} = \frac{600}{0.024} \quad (8)$$
$$NT_{max} = 158.1$$

A difference of 119 trains per day is fairly big and should therefore also have an influence on the overall maintenance costs. This can be realised with the use of information from railway operation simulations. With RailSys® the number of vehicle crossings can be recorded for each infrastructure element. This has been done for every point along the chosen track section. Then based on experiences the critical number of vehicle crossings, after which preventive maintenance is necessary, has to be defined. The actual number of vehicle crossings (and the train weights) retrieved from the simulation and the critical number determined by persons in charge are the input factors affecting the number of needed preventive maintenance cases.

The evaluated maintenance scenarios are defined as shown below. The time-based interval of 2 months is taken as an example from the German Railways guideline 892. If seen from a load perspective a maintenance interval of 2 months means that preventive maintenance is done the earliest after 2373 (=14235/6) and the latest after 9611 (=57670/6) vehicle crossings for tracks with a normal traffic volume. These two extreme values are needed when setting up maintenance scenario 2 and 3. For scenario 2 6000 vehicle crossings as a value in-between 2373 and 9611 has been chosen and for scenario 3 9500 vehicles as a value close to the upper extreme value of 9611 has been selected.

Scenario 1: - Time-dependent preventive maintenance
- Scheduled maintenance after 2 months

Scenario 2: - load-dependent preventive maintenance
- scheduled maintenance after 6000 vehicle crossings

Scenario 3: - load-dependent preventive maintenance
- scheduled maintenance after 9500 vehicle crossings

With the use of the developed tool link the preventive maintenance costs for a time period of 5 years and 67 points along the track section have been calculated. Both total values as well as NPV have been determined. In Table 2**Fehler! Verweisquelle konnte nicht gefunden werden.** the relative differences in the NPV of the costs for preventive maintenance based on a load-dependent concept (scenario 2 and 3) compared to the use of scheduled maintenance (scenario 1) are shown.

Scenario	NPV of the costs for preventive maintenance
Scenario 1	100 %
Scenario 2	21 %
Scenario 3	13 %

Table 2: NPV of Preventive Maintenance costs for a 5 year period for the chosen track section

Kommentar [BJ2]: Bitte UNTER die Tabelle und Kosten RELATIV darstellen!!!

Since the chosen track example is more on the minimum side of the load category for normal railway traffic the potential cost savings are comparatively high. In addition there is a high difference between the loads for each point. This means some of them are almost not used whereas others are used almost for every single train running on the track section. Even though there might be some chosen boundary conditions which are not close to practise a reduced NPV of costs for preventive maintenance of ca. 79 to 87 percent compared to the current situation at the German Railways shows the saving potentials if there would be a more load or condition-based maintenance.

6. SUMMARY

The presented approach demonstrates the need for changes in the maintenance management at the German Railways. The results presented in this paper show how information used for train scheduling with railway operation simulation software can be used to take a first step towards a more load and therefore also more condition-based maintenance concept for points. The advantage of this idea is that contrary to condition-based maintenance based on monitoring no additional equipment is needed. The maintenance managers are only asked for evaluating additional data from railway operation. But it is clear that the success of this idea depends on the flexibility of the maintenance system and the involved staff. The full cost optimisation potential can only be obtained when each point is maintained when necessary and maintenance staff is deployed as flexible as possible. In practise both aspects have to be considered especially when thinking of costs generated because of the time needed to get to and away from the location of a point. When thinking of the reduction of costs for preventive maintenance the persons in charge also have to keep in mind the interaction between preventive and corrective maintenance. It cannot have a positive effect on the overall life cycle costs of a point to reduce the amount of preventive maintenance work and accept a higher need for corrective maintenance work. This trade-off has almost no optimisation potential since corrective maintenance is needed when there is a component failure which then causes difficulties in the railway operation which as well is expressed in cost figures. To sum up, the idea of using railway operation simulation information for optimising maintenance concepts contains a high cost optimisation potential. The next step has to be the inclusion of further information about the maintenance procedures and processes to fully exploit the cost saving potential in practise.
Of course, the presented approach can be used for any track equipment, but is only needed when wearout depends on the load on the track.

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