

# Advancing life-cycle-management for railway signalling and control systems

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**Abstract** The railway system is one of the most environmentally friendly transportation systems. It is characterized as highly energy efficient, safe in operation, and low in CO<sub>2</sub> emission. The lifespan of its assets is extraordinary long, the operation is supposed to be highly reliable. Therefore the assets require life cycle management adapted to the specific demand of railways. There have been significant advances in the areas of rolling stock as well as roadbed and track. The railway control and signalling system ensures the safe and high performance operation of trains. At the Institute of Transportation Systems at DLR, a research team specialized in life-cycle-management for railway signalling systems focuses on how these challenges can be met. The aim is to further improve the railways sustainability and its share along other modes of transportation. This paper describes tools and methods to advance life-cycle-management for railway control and signalling systems.

## 1 Introduction

The railway system is one of the most environmental friendly transportation systems. It is characterized as highly energy efficient, safe in operation, and low in CO<sub>2</sub> emission. The lifespan of its assets is extraordinary long, the operation is supposed to be highly reliable. Therefore the assets require life-cycle-management (LCM) adapted to the specific demand of railways. There have been significant advances in the areas of rolling stock as well as roadbed and track. Thus, this paper focuses on the challenges of improving the railway control and signalling (RCS) systems along their life cycle. The RCS components (e.g. signal, level crossing, track clear detection, point machine, interlocking) ensure the safe and high performance operation of trains.

The lifespan of about 25 to 50 years already has to be considered during the development phase of the systems. This especially affects spare parts supply

which needs to be ensured over the whole operational phase. Furthermore, the RCS systems of a railway network will have to be constantly renewed. This results in a heterogeneous picture of the systems in operation. Standardized interfaces, components, and architectures are not yet widely used.

The dimensioning and planning of infrastructure and its corresponding RCS is a complex task. Numerous judicial, technical, operational, and financial restrictions have to be taken into account. Nowadays the infrastructure is often equipped with signalling systems that do not meet the expanding traffic demands. Systems are often optimised to costs of acquisition and therefore leaving important figures unconsidered (e.g. the number/duration of breakdowns or the amount of delays during the lifespan). For this reason, proper methods and tools are required to allow planners and managers to optimise the complex system according to life cycle costs (LCC), mobility needs, public benefit, and environmental impact. The maintenance of the RCS systems during the operational phase is essential for their safety and performance. Inappropriate maintenance strategies result either in high failure rates or extensive maintenance costs. The issue is even more challenging as rail networks are spatially distributed across huge areas. Thus maintenance activities along the numerous assets have to be well coordinated.

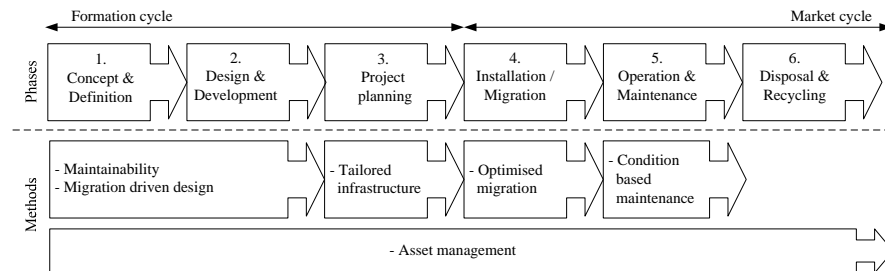
In order to advance LCM for RCS systems, tools and methods have been developed for each phase of the life cycle. In each phase, they are of high value for the optimisation of the LCC. Nevertheless, they unfold their full potential when being combined. This can be achieved by sharing data and results. In the presented concept, this task is carried out by an asset management. Because of the heterogeneity of the technical systems in use and their long life span, the comparison of information on a components level is inappropriate. Therefore, a functional approach has been chosen. It enables the decision maker to compare different technical and operational solutions as well as systems from different generations.

## **2 Life cycle of railway control and signalling systems**

To advance the LCM of RCS systems, this approach covers all relevant phases during the life span. Fig. 1 shows these phases and the methods applied. According to [1], the life cycle parts in two sections, i.e. the formation cycle and the market cycle.

The first two phases of Concept & Definition as well as Design & Development refer to the manufacturer of the RCS system. Considering the long life span of up to 50 years, maintainability has to be in the main focus during these phases. In

most cases there are legacy systems in use when the new RCS system is installed. This bears constraints which have to be considered as early as possible with a migration driven design. Only if the new system fits in the existing surrounding, the migration of the new system will be successful.



**Fig. 1: Life cycle phases of RCS systems and proposed methods**

During the third phase, the railway infrastructure is planned. Here, the performance, the height of the investments and the costs for operations and maintenance of a track section are defined. It has to be the aim to satisfy the performance requirements with minimal costs. To achieve this, the software tool Railonomics<sup>®</sup>-Infra has been developed.

When a new generation of a RCS system is applied to a railway network, complex panning problems for the migration of this system arise. This takes place within the fourth phase of installation and migration. The change of the RCS on one section of a network mutually affects this particular section and the rest of the network. This is caused by two facts. First, the compatibility of RCS systems of vehicles and infrastructure is required. Secondly, the vehicles are supposed to move over the whole network. To handle this, the software tool Railonomics<sup>®</sup>-Migration has been developed.

In the fifth phase of Operation & Maintenance, the occurring costs can be reduced significantly by using condition based preventive maintenance. This is achieved by continuously monitoring the condition of the RCS systems. Thus, the best point in time to carry out the maintenance can be found.

In parallel to the before mentioned methods, an asset management is carried out. It enables the share of information between the life cycle phases. Also, decisions about the end of life of RCS systems are based upon it.

## ***2.1 Development***

For network based technologies like the railways, the ability for renewal and replacement of systems is bound to numerous constraints. This is determined by

the fact that the value of a network technology is mainly defined by its size [2]. The compatibility of the legacy and the new technology is an essential issue during the design and development phase. Also, when the new technology is introduced, the system as a whole has to stay operational. Additionally, the systems in use by the railways are very heterogeneous. Thus, new technologies have to be very adaptive.

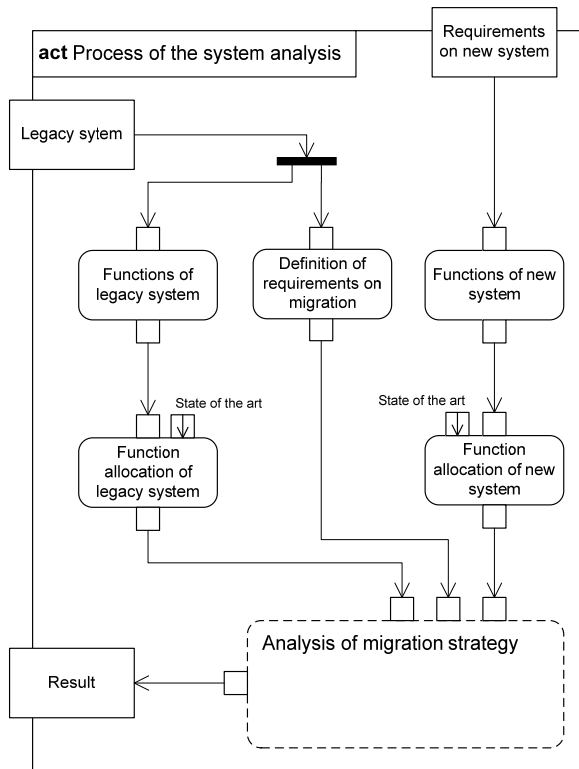
When new technologies are developed, their whole life cycle has to be considered. This leads to the requirement to make the migration of later generations of the technologies or the partly renewal as easy as possible. For the new development, the life cycle of the system should not be determined by its component with the shortest life span as it is today. Hence, the functionality of each component has to be carefully considered and a standardised design of interfaces needs high attention.

Thus, the requirements for a migration driven design of new technologies in railways should take legacy and future systems into account. The design must keep the costs of the migration low and therefore enable a quick accomplishment of the migration. The additional value of the new compared to the legacy system has to be realised shortly after the installation. [3]

To satisfy these demands, the systems are described on a functional level first. Past and present functions can be applied and analysed. The shift of the functions between the components from the legacy to the new system becomes visible, see Fig. 2. On the left hand side, the legacy system is described with its functions and components. The right hand side displays the new system. Both systems share functions. These have to be fulfilled by components before, during and after the migration. Functions which only belong to the legacy system are no longer available after the migration is accomplished.

Each function delivers a value and each component causes specific costs. So, the functional analysis of the migration process in Fig. 2 offers the possibility to optimise the system design and the migration itself.

The consideration of the migration process during the system design allows to speed up the migration, gain additional value early, and to reduce the costs of the migration. Carefully chosen and standardised interfaces enable a partial renewal in the future. The system becomes more sustainable.



**Fig. 2: Functional analysis of the migration process**

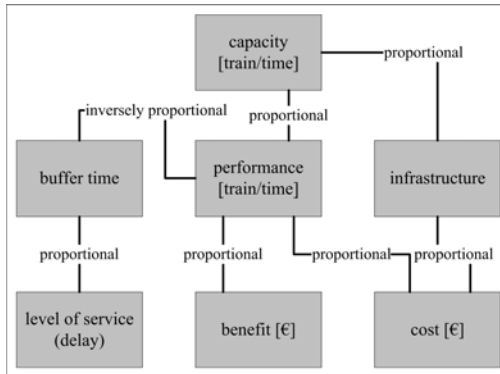
## ***2.2 Project planning***

In the planning phase of the infrastructures life cycle, the infrastructure and RCS systems will be optimised. In most cases, it is the goal to achieve a high capacity of utilisation (performance [train/time]) without capacity overload. Capacity overload causes an instable timetable, which generates heavy delays based on light incidents. A low quality of operation (level of service) would be the result.

The infrastructure should be optimised due to the expected total traffic to achieve a maximise performance at a maximised level of service. The expected total traffic is difficult to estimate. Thus the total traffic (for example as timetables) will be evaluated for different scenarios to ensure sustainability. According to that, in many cases the infrastructure will be optimised with the help of a high number of timetables.

Railway operation simulation tools have the purpose to analyse the interaction between timetable, capacity of infrastructure, and quality of operation. Therefore parameters which determine the performance must be known, e.g. the timetable, and capacity of the infrastructure, e.g. type and position of the signals, switches, signal boxes and the number of tracks. Elements like track gradients and driving dynamics of the trains affect the performance and capacity, and have to be included in the simulation model as well. With the use of stochastic distributed incidents and whose influences the level of service can be determined at defined infrastructure and timetable.

The optimal infrastructure can be adapted to the expected total traffic through operation simulation tools. Under certain circumstances a high number of simulation runs is needed to determine the optimal infrastructure. To also determine the economically advantageous one, the LCC of the infrastructure of each simulation run must be known (see Fig. 3).



**Fig. 3: Dependencies of performance and infrastructure**

To do this in a manageable way the tool Railonomics<sup>®</sup>-Infra is developed. This tool includes a database to estimate the LCC and income by track charges of the infrastructure. Furthermore, it includes an interface between the database and the simulation tool based on the xml-format railML<sup>®</sup>. As a result, information about the modelled infrastructure and output of the simulations can be integrated in the Railonomics<sup>®</sup>-Infra tool in an easy and semi-automatic way. [4] [5]

The economic efficiency of an infrastructure can be determined with its LCC and the income through performance, i.e. track charges. The infrastructure also generates further benefits which are not rateable as monetary units, such as safety or special functionalities of signal boxes etc. Therefore a value analysis can be added.

The combination of simulation tools and a tool for LCC and benefit calculation is very advantageous if a high number of infrastructures and/or timetables are examined to determine the most economic efficient and sustainable one.

### ***2.3 Installation and migration***

For network based technologies like the railways, the change of technology has to take place without interrupting the operations. Such a process is described as a technology migration. An interruption of the operation reduces the networks size and benefit. Therefore, it is necessary to proceed with a highly coordinated migration strategy and to commit to technical standards [6]. Also, safety and performance have to be extended or maintained, resulting costs have to be minimized, and benefit from the new system has to be gained quickly. The main challenge of the migration is the huge number of relevant parameters, constraints and dependencies. The migration of vehicles and infrastructure has to be coordinated and optimized. Furthermore, the complexity is increased by the long life span of railway technology.

The presented method takes these constraints and parameters into account. From this baseline, migration strategies are developed and evaluated. Fig. 4 gives a brief overview of the method which is implemented in a tool Railonomics<sup>®</sup>-Migration as well. [7]

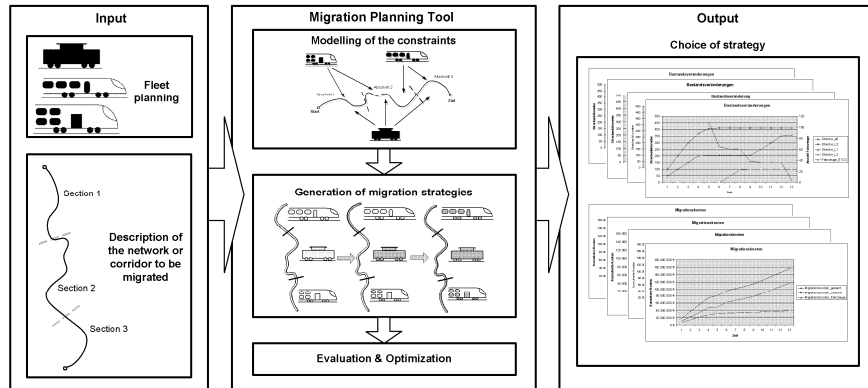
The first step of the method is the collection of constraints and parameters, i.e. the identification of the network to be modelled. In this context, constraints are factors that cannot be changed during the migration. On the contraire, the choice of parameters is free to a certain extent. The left box of Fig. 4 shows this step.

A modelled rail network consists of one or more line sections and one or more vehicle pools to include the traffic. This can be seen at the top of the middle box in Fig. 4. The vehicle pools are assigned to the line sections to match the flow of traffic. Additionally, it is important to regard how many kilometres and vehicles per year can be equipped with the new system, and how quick the legacy system can be taken off the track. It has a major effect on the resulting strategies.

The definition of the sections of the corridor and the related traffic describes the initial situation of the migration. The next step is to derive the scope of migration goals, as shown in the middle of the second box of Fig. 4. Those which do not meet the requirements of the traffic cannot be part of resulting migration strategy. Hence, each allowed migration goal on each line section has to meet the highest requirements of the related traffic.

The generation of the migration strategies delivers the changes of the examined assets over time. From this baseline, a cost driver is assigned to each asset and element, shown in the lowermost part of the middle box in Fig. 4. This yields the possibility to derive different performance figures, like the net present value, life cycle costs, or migration costs.

As an output of the method, the decision maker receives few optimised strategies, as shown on the right side of Fig. 4. Now, further criteria like the performance can be applied for the final choice.



**Fig. 4: Optimisation of migration strategies**

No matter which strategy is chosen based on the method, it is assured that all relevant constraints were taken into account. It enables the migration towards a more competitive railway cost effective ways. The constant and coordinated renewal of the technology ensures the sustainability of the railway system.

## 2.4 Operation and maintenance

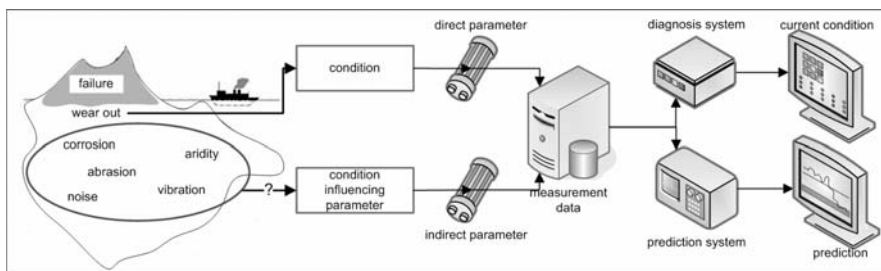
A lifespan of 25 to 50 years means that, despite all new technology and methods, the vast majority of systems currently in use will be operated without such improvements for the upcoming 15 years. Hence, research on LCM needs to present solutions to reduce the cost of operation, which are mainly the result of maintenance and repair. The optimisation of maintenance promises cost reductions of 20 to 30 percent [8]. In Germany the currently implied maintenance strategy for the railway infrastructure is based on a prescheduled fixed time interval [9]. Condition based maintenance would be a much more cost efficient strategy. But it requires a continuous condition monitoring, and a reliable condition diagnosis and prediction to meet the high safety standards for RCS systems [10]. To apply condition based maintenance the research focuses on the condition diagnosis and prediction of points (aka switches) in a first step. Points are critical. They connect different tracks and allow a train to change its moving direction without stopping. Their breakdowns cause a relatively high proportion of all delayed minutes (19% according to [11]).



The point itself is assigned as track bed infrastructure element, while the point machine (aka switch engine), which is moving the tongues, is assigned to the RCS. Several point diagnosis systems exist on the market. They measure the electronic power consumption of the point machine during the repositioning of the point. The measured parameters indicate the state of condition or reveal failures of the point [12]. The measurement data from 29 points during March 2007 and March 2009 (ca. 294,000 tuple) had been analysed by members of the LCM research group. The results show that point diagnosis systems alone are not sufficient enough to provide a reliable condition diagnosis, because there are too much external influences producing noise in the measurements [13].

To overcome these issues other parameters which directly or indirectly influence the point condition (e.g. air temperature, number and axle load of trains crossing) had been integrated to establish diagnosis and enable a condition prediction. Methods from the field of artificial intelligence and data mining are used to develop the condition prediction model. Therefore a broad knowledge regarding the point architecture, functionality, and deterioration process is necessary to select the appropriate parameters and fine tune the prediction model (see Fig. 5). Once the main relevant condition influencing parameters had been identified using (cross-) correlation analysis, different methods (e.g. Clustering, Match Matrix with ARMA, Neural Networks) had been combined to determine the probability of days to the next failure of a particular point.

Though the development of a prediction model is yet not finished the current progress shows that the chosen approach is promising. The prediction of the condition will enable maintenance managers to optimise the planning of maintenance activities and also save money by increasing the failure-free operation time, avoiding unnecessary maintenance activities, and optimising the stockpiling of spare parts. It will also reduce partly dangerous maintenance activities in the track bed.



**Fig. 5: Process of understanding degradation and processing measured data for diagnosis and prediction**

### 3 Asset management

Industries using complex, long-living and capital-intensive technologies require special focus on handling these assets at all management levels - be it operational with focus on day-to-day maintenance, be it strategic and in the long-run. RCS technology is a perfect example of that, having to deal with huge asset pools consisting of several generations of safety-relevant technologies.

In order to ensure successful business the different tools, methods and approaches towards advancing LCM need to be integrated in a comprehensive concept for asset management adapted to the needs of railways, as described in [14].

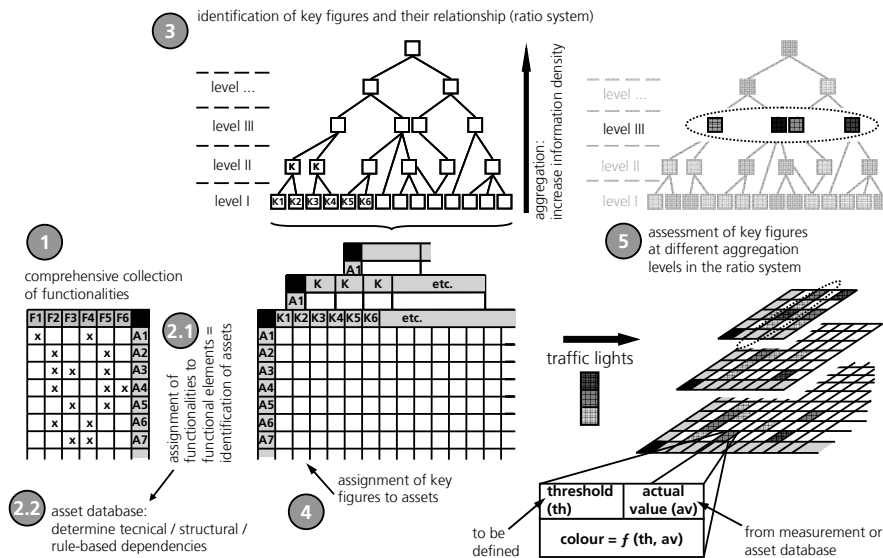
Basis for the determination of indispensable assets is a comprehensive and complete collection of the functionalities to be fulfilled for the object of the enterprise (step 1 in Fig. 6). The functionalities are assigned to functional elements (similar to the approach in chapter 2.1). These elements form the assets to be managed (step 2.1). Typically a technical component covers several functionalities. This approach helps to focus on requirements that are essential for the specific business. It is the necessary basis for any migration decision and for tailored application of infrastructure e.g. with Railonomics<sup>®</sup>-Infra.

Specific for the railway domain are proprietary technologies (e.g. interlocking systems) of different system providers. Single components of different suppliers cannot be exchanged without further ado (adaptations, recertification etc.). Components within a system affect each other due to technical, structural and rule-based dependencies. To avoid wrong decisions, these constraints have to be observed. All information on the assets and their dependencies need to be gathered in an asset database (step 2.2).

As an effective instrument to monitor the status of the asset pool a ratio system combining the key figures of the assets can provide information for all management levels, depending on the aggregation of the figures (step 3). These figures need to be developed and assigned to the assets which they can be applied to (step 4). The figures vary over time and depend e.g. on the condition of the components under surveillance. These information are also important to advance the development of new technologies, e.g. with the focus on maintainability.

To provide support for appropriate decision making, thresholds for the figures can be set, allowing for automated triggering of actions of the management in order to control the development of the asset pool (step 5). As figures out of various domains have to be compared, visualisation by colours - e.g. like traffic lights - can provide clear view of the status of each asset at a glance.

This comprehensive asset management concept needs continuous updating and provides an approach for successful long-term management of complex asset pools.



**Fig. 6: Comprehensive asset management concept for complex technologies**

## 4 Summary

The goal of the advancement of life-cycle-management for RCS systems is to retain the sustainability of the railway. Long life spans, high investments, spatial distribution of the systems, and heterogeneous technologies in use characterise these systems. Tools and methods for each life cycle phase like Railonomics® and condition based maintenance address these constraints. An asset management system ensures the share of information between phases and participants. With these measures, a step towards a constant renewal and improvement of the railway system has been taken. Thus, advanced competitiveness considering costs and performance compared to other, less sustainable transport modes can be achieved.

## 5 References

- [1] DIN EN 60300-3-3 Dependability management – Part 3-3: Application guide – Life cycle costing (IEC 60300-3-3:2004). German version.
- [2] Katz, M., Shapiro, C., Network Externalities, Competition and Compatibility, *American Economic Review*, Vol. 75, 1985, pp. 424–440.

- [3] Lackhove, C., Kohlruss, J., How expensive is a telematic system allowed to be? - A method to support finding target costs, EurailTelematics, Berlin (Germany), 2010, Vol. 4, pp. 22-24.
- [4] Beck, K., Scheier, B., Jäger, B., RAILONOMICS® – Determining Investment Strategies for Railway Signalling through Simulation. In: Computers in Railways - Computer System Design and Operation in the Railway and other Transit Systems, Toledo (Spain), 2008, Vol. 11, pp. 65-74.
- [5] Böhm, Thomas und Scheier, Benedikt, Railonomics - für eine bedarfsgerechte Infrastruktur, *EI - Der Eisenbahningenieur*, Vol. 61, No. 1, 2010 , pp. 32-36.
- [6] Bolli, M., Rothbauer, M. F., ERTMS/ETCS – the future has begun, *Signal und Draht*, Vol. 101, No. 3, 2009, pp. 6-12.
- [7] Lackhove, C., Jäger, B., Lemmer, K., Generating and optimizing strategies for the migration of ETCS, Computers in Railways - Computer System Design and Operation in the Railway and other Transit Systems, Beijing (China), 2010, Vol. 12, pp. 383-394.
- [8] UIC Infrastructure Commission (Union Internationale des Chemins de Fer), InfraCost – The Cost of Railway Infrastructure, Final Report, Paris, 2002.
- [9] Friedrich, N., Instandhaltung bei der DB Netz AG, *Deine Bahn*, Vol. 37, No. 1, 2009, pp. 20–23.
- [10] Gutsche, K., Böhm, T., eMaintenance for Railway assets - Challenges within the creation of a prediction model, The 1st international workshop and congress on eMaintenance, Lulea (Sweden), 2010.
- [11] Rausch, W., Diagnosesysteme für Weichen als Grundlage für eine optimierte Instandhaltungsplanung, Symposium - Moderne Instandhaltungsverfahren für Weichen, Kirchmoeser (Germany), 2010.
- [12] Bollrath, B., Sattler, U., Weichendiagnosesystem Sidis W – Betriebliche Erfahrungen, *ETR - Eisenbahntechnische Rundschau*, Vol. 55, No. 10, pp. 734–735.
- [13] Böhm, T., Doegen, C., Diagnosis without Sensors: Integration of External Data for Condition Monitoring of Railway Switches, Proceedings of the 23rd International Congress on Condition Monitoring and Diagnostic Engineering Management, Nara (Japan), 2010, Vol. 23, pp. 619-622.
- [14] Gutsche, K., Brinkmann, F., Ganzheitliches Management von Anlagen der Eisenbahninfrastruktur, *Signal und Draht*, Vol. 102, No. 11 , 2010, pp. 27-31.