Modelling degradation processes of switches & crossings for maintenance & renewal planning on the Swiss railway network

First results from the literature study

Willem-Jan Zwanenburg, EPFL - LITEP

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Willem-Jan Zwanenburg
EPFL - ENAC - LITEP
Station 18
CH - 1015 Lausanne

Phone: +41 – 21- 693 63 01
Fax: +41 – 21 – 693 50 60
email: willem-jan.zwanenburg@epfl.ch

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Abstract

Switches and crossings (S&C) form an important asset of modern day railways. Current Decision Support Systems for track maintenance and renewal however do not provide help on maintenance and renewal management of S&C, due to the lack of understanding of the degradation and deterioration processes of S&C often combined with an unsuitable way of data collection.

This project will focus on understanding and modelling the degradation and deterioration processes of complete S&C and its components (ballast, sleepers, rail, frogs/crossings, sliding chairs, half set of switches etc) on geometrical scale and with regard to material deterioration. In close cooperation with the Swiss Federal Railways (SBB) and – if possible – other networks through the International Union of Railways (UIC), information will be gathered on S&C deterioration in combination with information on the trains which run over the S&C, the number of settings, axle loads, speeds, quality of the subsoil etc. The end product will consist of models and a computer tool which allow future prediction of maintenance and renewal needs of S&C on network, regional and local scale.

Keywords

railway – maintenance – renewal – decision support – network management – switches – turnouts – deterioration – reliability based maintenance

On the front page: switches and crossings at Zürich HB (main station)

1. Introduction

Railway switches and crossings (S&C) are representing an important asset of railway networks. Approximately 25.000 of these devices allow the trains on the Swiss railway network to run as they do today. In case of disruptions they form an even more important asset, allowing for trains to use other routes than usual, or to use a track in the opposite direction, to assure a reliable train service for the passengers. This however comes with a cost: 20 to 40 percent of the track maintenance budget is spent on the inspection, maintenance and renewal of S&C. This relative high expenditure (the maintenance cost of one switch or crossing equals the maintenance costs of 300 to 500 meters of plain track) is mainly due to the nature of S&C that makes them absolute and relative more expensive to maintain than plain track (straights and curves):

- S&C have special components e.g. switch tongues, frogs, slide plates, exposed to high static and dynamic forces, thus showing high wear rates and specific deterioration;
- S&C have moving parts, which require extra regular inspections and maintenance actions e.g. greasing, to avoid poor reliability;
- S&C form a potential safety hazard, due to moving parts, which in case of malfunctioning (or worse: breaking) can immediately cause serious accidents, thus requiring immediate action in case problems are detected – where simple track sometimes can sustain its function due to built-in redundancy.

For plain track Decision Support Tools have been developed during the last two decades (e.g. EcoTrack at LITEP[1] since 1990), to compare different maintenance and renewal policies, reduce costs and improve reliability. The strength of these tools is the capability of dealing with large amount of data on complete railway networks, thus providing network overviews on maintenance and renewal needs.

While for plain track for different geometrical degradation modes (e.g. cant, twist, level, gauge) and component deterioration (e.g. cracks, gauge corner cracking, head checks, (wave) corrugation) the relation with the track load is known, the knowledge on degradation and deterioration processes of switches and crossings has been rudimentary. This paper will present the first results from the literature study on this subject and the methodology which will be used to derive models from the data.

[1] Rivier, R.E. (1999) "Life Cycle Cost Analysis and EcoTrack: Economical Track", UIC Headquarters, Paris

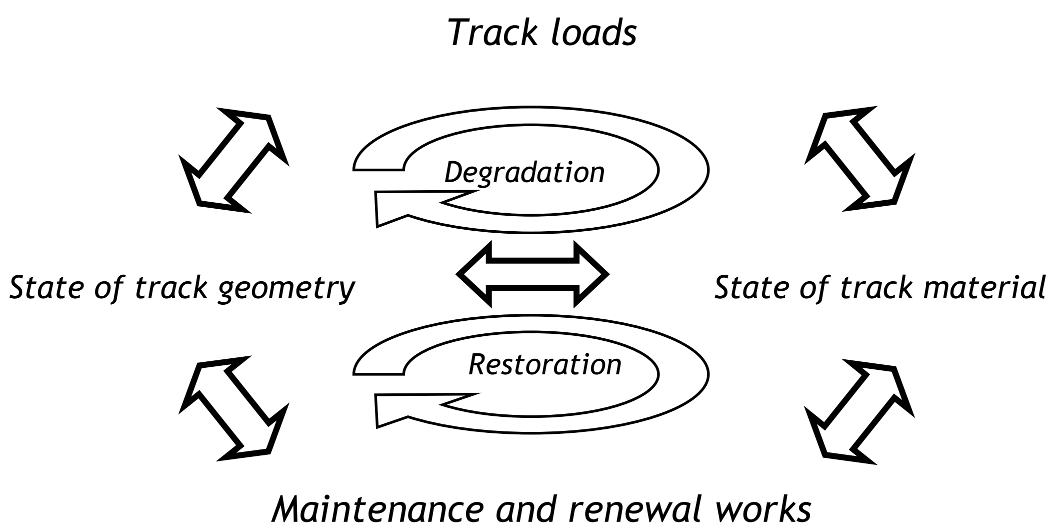
2. Degradation of railway track

2.1 Degradation parameters of plain track

Trains running over railway tracks cause degradation of these tracks and its components (rail, rail fastenings, railpads, sleepers, ballast etc.). The speed of this degradation depends mainly on:

- the track geometry: train tracks in bad geometrical condition will cause “rollercoaster”-behaviour of the train, which results in higher dynamic loads from the train on the track;
- the state of the track material: bad sleepers or worn rails will provide a unsmooth running path, resulting in vibrations, which as a result cause faster degradation of other track components.

Figure 1 Model for the degradation and restoration of railway track (components)



Source: Rivier, R.E. (2002) ; Lecture notes “Maintenance d’ouvrages et d’infrastructures” – “Gestion de la maintenance des réseaux ferroviaires” ; EPFL - LITEP

Beside the relation – regarding rail track degradation – train loads vs. track geometry and. the state of the track material, there is also a relation between track geometry and the state of the material: bad material causes more track geometry degradation. This relation is also valid the other way: bad track geometry will in the same negative way affect the state of the track material.

To repair the bad track geometry, maintenance and renewal actions like tamping and grinding are carried out. To repair worn track materials, they can be replaced or repaired at site.

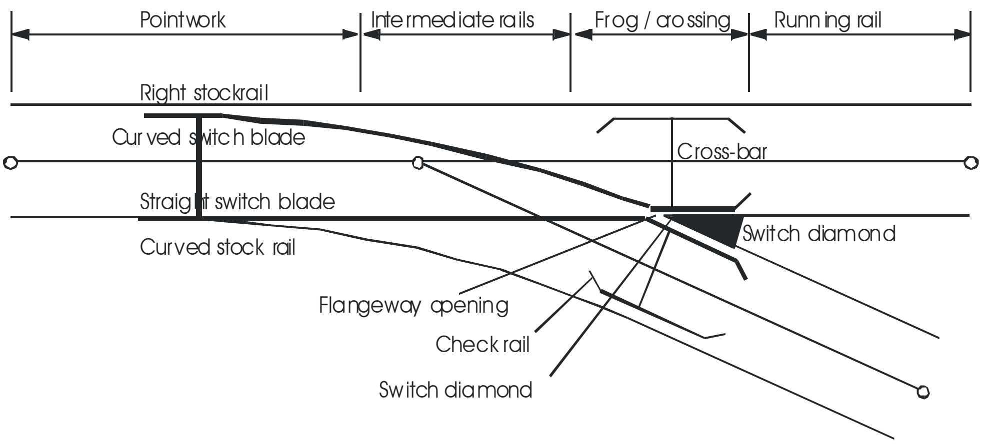
The above described relations are all presented in figure 1.

The track load which cause the degradation of track geometry and track material can be divided into several different parameters, affecting the degradation rate: train speed, type and condition of the trains and axle loads. Track parameters influencing the degradation rate (beside geometrical state of the track and the state of the materials) are e.g. the sub-base condition or the quality of installation. Material parameters which have an influence are e.g. metal hardness or running surface profile.

2.2 Degradation parameters of switches and crossings

The terms described in the previous paragraph count for plain track degradation. Studies have shown that these also count partially for switches and crossings (S&C). However some specific parameters have to be taken into account due to the special construction of a switch or crossing.

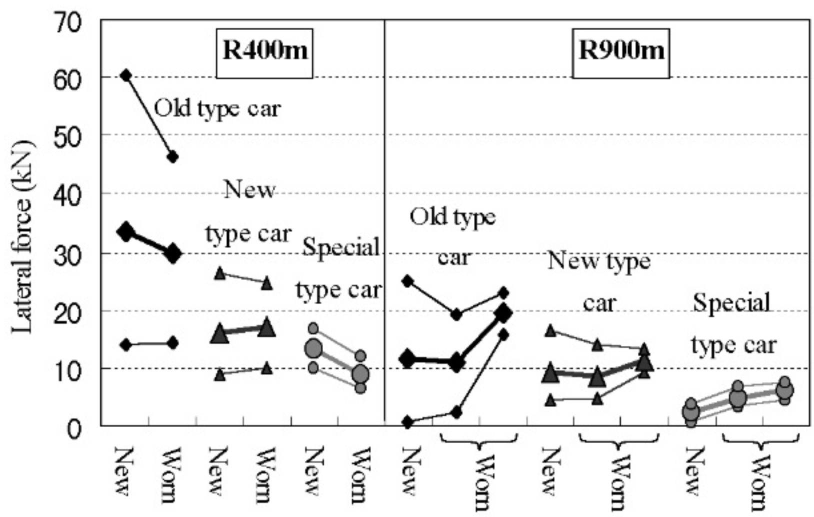
Figure 2 Schematic model of a simple turnout (switch) with terminology



Source: Rivier, R.E. (2000) ; Lecture notes "Superstructure de la voie ferrée" – "Gestion de la maintenance des réseaux ferroviaires" ; EPFL - LITEP

A simple turnout as presented in figure 2 consists of a straight direction ("through" or "main" direction) and a curve (or diverting direction). In reality, a switch can also consist of two curved sections. To reduce costs, a switch generally has a limited length, leading to a small curve radius and short transition curve[2] in the curved direction. Beside this, no cant (superelevation) can be introduced like in normal curves, where the outer rail is in a higher position as the inner rail to partly compensate the lateral accelerations and thus provide a smoother ride for the passengers. A switch can therefore be passed only with limited speed in the curved direction. This speed limit depends on the curve radius and the maximum lateral acceleration and jerk (change in acceleration) allowed. For exploitation reasons sometimes a high speed in the curved direction is necessary, like on high speed lines (e.g. Mattstetten-Rothrist). Therefore a switch with a large radius curve can result in a total switch length from switch blade to switch diamond of up to 200 meters.

Figure 3 Lateral forces of new and worn outside rail caused by leading axles in two different curve radii (400 and 900 meters)



Source: Ishida, M. et al. (2001) "Gauge Face Wear Caused with Vehicle/Track Interaction"; Proceedings of the World Conference on Railway Research 2001

The speed of the train in the curve and the curve radius lead to a lateral acceleration: train passengers feel this as if they are pushed sideways in their chairs. Not only train passengers feel this, also the forces exceeded by the train on the track in the lateral direction increase in this situation, which leads to extra wear of (mainly) rail components. Several studies have shown this (e.g. figure 3).

[2] A transition curve is the connexion between a straight and a curve, where the radius is slightly reduced from the straight (curve radius ∞) to the radius of the curve (e.g. 400 meters or 1000 meters).

Ishida et al.[3] have not only shown the wear rates for plain track curves with 400 and 900 meter radii (similar to curve radii in S&C), but also that the type of train is important (Ishida et al. used 3 train types shown in figure 3). Although in the curves used by Ishida et al. (and also on other plain track tests) a slight cant is applied on the track, the results still remain valid for S&C without cant. In general the amount of non-compensated lateral acceleration as calculated with

$$Y_{centr} = m \cdot a = m \cdot \frac{v^2}{R}$$

in which:

Y_{centr} : lateral force [kN]

m : mass or axle load [kg]

a : acceleration [m/s^2]

v : speed (velocity) [m/s]

R : curve radius [m]

can be used as a proper estimation of the forces exceeded in a switch. The term v^2/R is also known as the centrifugal acceleration.

Other significant wear or degradation parameters are the jerk (change in acceleration), caused by the short transition curve[4], number of settings and (related with the jerk) the strike angle of the wheels[5].

The parameters mostly affect all components of S&C. Although for example the strike angle of the wheel only has a direct effect on the switch blade wear, the resulting dynamical forces (vibrations) are via the rail seats and sleepers transmitted to the ballast and to other nearby components, with wear of these components as a result.

[3] Ishida, M. et al. (2001) “Gauge Face Wear Caused with Vehicle/Track Interaction”; Proceedings of the World Conference on Railway Research 2001, Cologne, Germany

[4] Bugarin, R. et al. (2002) “Turnouts, evolution in the last 20 years and new challenges”; Proceedings of the Switch to Delft Conference 2002, Delft, the Netherlands

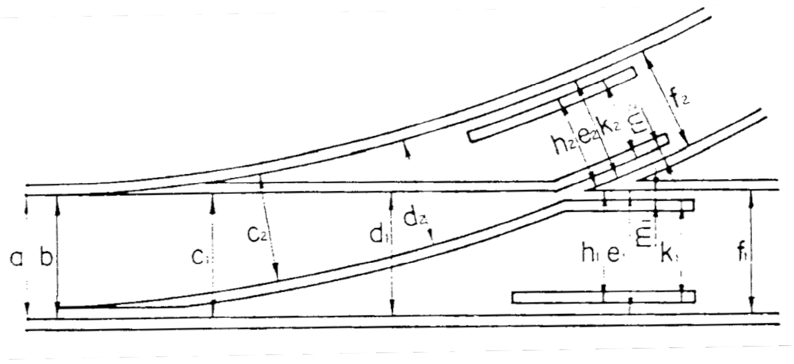
[5] Ulrich, D. & Luke, M. (2001) “Simulating rolling contact fatigue and wear on a wheel/rail simulation test rig”; Proceedings of the World Conference on Railway Research 2001, Cologne, Germany

2.3 Measured wear parameters of switches and crossings

The high amount of parameters affecting S&C wear, are not all measured. On the contrary: for example forces exceeded by the train on the rail are rarely measured. Twice annual measurements of plain track condition however can be valuable for this purpose. Nowadays these measurements are mostly thrown away when it comes to S&C, because they form "noise" on the measurements of plain track. They can be used for this study.

The rest of the measurements on S&C wear more or less rely on measurements by hand with regular intervals of several geometrical parameters, of which the limits for maintenance and renewal are well defined.

Figure 4 Geometrical parameters measured at tram and metro S&C of "Wiener Linien"[6]



Source: Wiener Linien[7]

The measurements with regular intervals nowadays lead to repairs and renewals on relative short notice: a couple of weeks or months for components, a year or more for a complete switch. For plain track, forecasts of the maintenance and renewal needs for (tens of) years ahead are already possible, allowing maintenance needs to be foreseen and spread: if in a certain year (or years) a lot of maintenance is expected, some of it might be carried out earlier, to avoid a work overload in certain year and optimize the use of resources.

[6] Public transport company in Vienna, Austria

[7] published in: Jovanović, S. & W.-J. Zwanenburg (2002) "Switches and Crossings Management System: EcoSwitch – Feasibility Study" ERRI D251/RP1; European Rail Research Institute, Utrecht Netherlands

3. Problem approach and work method

In the previous chapter different parameters for the degradation of switches and crossings (S&C) are described. Some of these parameters are measured, others are only measured indirectly. To find models for the degradation, only the measurements already available are used. In general there are two different approaches for the problem: an engineering approach[8] and a statistical approach.

3.1 Engineering approach

The engineering approach consists of establishing, by theory and testing, the mechanical properties of all elements that make up the track structure and the railroad vehicles, which run over it. By applying the calculated or simulated static and dynamic loads of the trains and the calculated response of the track elements, permanent deformation can be predicted. This method requires exact description of mechanical behaviour of trains and track and has already proven its worth in different studies[9] [10].

3.2 Statistical approach

The statistical approach involves –in this case – the analyses of many observations of

- real up-to-date train loads (axle loads, total load, type of trains, direction of trains) over specific switches & crossings (S&C);
- measurements of degradation parameters of S&C or all other parameters measured currently of switches and crossings.

3.3 Choice of method

It is known that two switches of the same type with the same load (same amount and type of trains, equal axle loads, same directions etc.) can still show different deterioration rates for specific components. The engineering approach will then have only limited value. Although it might work for laboratory tests of components of S&C, in-situ, the results will have a certain

[8] Selig, E.T. et.al. (1981) "A Theory for Track Maintenance Life Prediction", U.S. Department of Transportation, Rept. DOT/RSPA/DPB-50/81/25

[9] Fischer, F.D. et al. (2005) "The Impact of a Wheel on a Crossing", ZEVrail Glasers Annalen 129, August, pp. 336-345

[10] Wiest, M. et al. (2005) "Finite Elemente Analyse des Überrollens eines Herzstücks, ZEVrail Glasers Annalen 129, November-Dezember, pp. 461-467

scatter and noise, which can only be limited by taking into account as much as possible S&C of which as much as possible information can be retrieved. At that moment the statistical approach might provide the most interesting results.

3.4 Work method

The first and most important step is to retrieve as much as possible information on as much as possible S&C as possible. However in co-ordination with the SBB it might be that limiting this search to a certain type of S&C or certain S&C in a certain area might result in faster availability of the information in case data availability is limited. This process is now on its way.

After establishing the first models with the statistical approach as presented in the previous paragraph, there can be a calibration of the models to check their validity for different types of S&C.

The next step is to define maintenance and renewal needs. Also during this step, in close co-operation with the SBB, models are derived this time regarding maintenance and renewal actions on S&C and their respective results and costs.

At the end a decision support tool will be developed.

4. Conclusion

A model for the degradation and deterioration of the geometry and material condition of switches and crossings (S&C) does not exist. However a need for it has been identified. In close co-operation with the SBB a model for S&C degradation and deterioration is currently in development. This study however is still in its early phase, with the literature study almost finished and the first data collection at hand. Taking into regard the highly professional collection and storage of information at the SBB (especially compared to other railway companies in Europe), next development steps can hopefully be taken successful and swift.