A HOLISTIC ASSESSMENT APPROACH FOR HIGH-SPEED LINES MAINTENANCE AND RENEWAL

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ABSTRACT

The French rail network comprises 30,000 km of lines including 2,600 km of high-speed lines. Thanks to specific equipment monitoring the track geometry, infrastructure managers can adapt maintenance operations like tamping and build track renewal programs (rail, sleepers, ballast). With the increase of traffic and the aging of track, maintenance operations to restore the track level are quite frequent. In this framework the renewal program (rail-sleeper/ballast or ballast) of the first European high-speed line built in the early ‘80s between Paris and Lyon is planned in the coming years. To guarantee the durability of these renewal works, a multi-domain approach to analyse the complete system: track, platform and environment is proposed. First an interactive database integrating the parameters related to the description, use, state and environment of the network has been created. Second an analysis of the database parameters affecting the durability of the railway structure and a methodology of prioritization on sections requiring finer analysis have been developed. The first results indicate that about 12% of the tracks require additional evaluation of the sub-ballast layers and / or hydraulic system. This methodology has been validated using investigations and in-situ observations and is now spread-out on other French high-speed lines.

Introduction

The durability of network railway rehabilitation works in terms of maintenance and the imperatives in terms of network performance require defining quickly and appropriately the network portions location requiring significant works and their nature. In this article, an approach enabling us to realize rapidly a diagnosis in order to prioritize sections that need civil engineering and specific additional analyses has been developed. This multi-domain approach helps to analyse the complete system: track, platform and environment by integrating in a database the parameters related to the description, use, state and environment of the network and by analysing parameters affecting the durability of the railway structure.

1. A holistic assessment approach for diagnosis

The design of classical line resulted in the development, under the ballast, of a "plugged" ballast layer, followed by a so-called "intermediate layer" horizon, which is usually stable and compacted by the successive passages of trains. This layer consists of an in situ ballast mixture by interpolation of the ballast in the ground in place.

The predominate design of line track structures is based on the classical ones. For the high-speed line it consists of a ballast layer which has been deposited on the subballast layer, the shape layer and the whole rests on the ground.

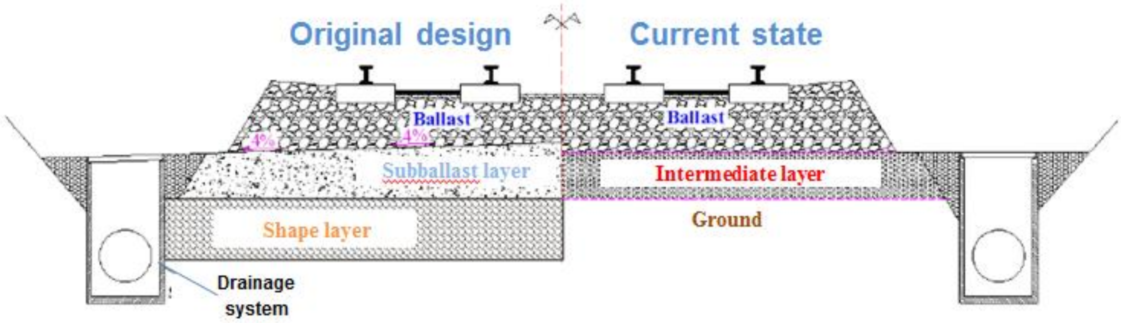

Figure 1 Comparison between classical and high speed lines structures (Source before adaptation: Cui et al, 2014 [1])

The SNCF program tracks inspections carried out twice a month by a specific train. The collected data are processed to indicate enabling managers planning maintenance or renewal actions.

To define pertinent and optimized solutions, the evaluation of the sustainability of track renewal work or the determination of areas according to their degree of vulnerability requires choosing measurable parameters [3]. Therefore, as for the classical lines [12], we propose a method to estimate the zones which are liable to rapid degradation according to three criteria: the network state, the network description and the external environment. Concretely for each 10m zone of the Paris-Lyon LN1 line, we evaluate a global criticality level. These indicators highlight the appearance of defects which may originate from disorders related to components of the track and / or variation in the structures of the railway platform, nature of the subsoil or poor drainage for example [6]. This new advanced data processing can help to extrapolate the LN1 case to the other lines.

2. Available data assembling and database structuring process

2.1. Input data

Three data chains were considered in accordance with the SNCF data governance:

- The network description
- The network state
- The external environment

Those data were then collected and assembled in an important database. To obtain a quite accurate analysis, it is important to choose an appropriate division step. The analysis can be adapted for portions of 5, 10, 50, 100 or even 200 m. A 10-m step was considered since a shorter one would have created too many localized cases to study but beside a too large one wouldn't have provided enough critical area by associating too many problems.

2.1.1. The network description

First of all, it is important to list the constitutive elements of the network railway area:

- Configuration of earthwork according to the 3 following categories: embankment, grading embankment and excavation
- Engineering works presence such as structural works, hydraulic structures, bridges…
- Engineering works constitution

Indeed, excavated earthworks tend to retain the water so the latter can contribute to platform disorders but can also disturb drainage capability. It was noticed that engineering works' proximity may also be the source of problems related again to water stagnation.

A more refined description of the network can be made via the identification of the nature and the type of the sleepers and rails. The older they are, the more difficult it is for them to support steadily the rolling stock. Furthermore, it was noticed that monoblock sleepers were much more stable than split units that can affect the rail linearity.

The traffic speeds and the daily tonnage are also considered since the faster and/or the heavier is the rolling stock, the more likely dynamic vibrations may lead to soil disturbances within the platform such as pumping effect.

2.1.2. The network state

Track geometry

Measurement of track geometry quality is the most used automated condition assessment technique in railway maintenance. Most problems with the track (at least the ones concerning the ballast and substructure) will be visible as track geometry irregularities, but the root cause of the problem is not detected with the help of track geometry measurements. We propose in our approach to focus on the Longitudinal Level (NL for "Niveau Longitudinal") variations. The main parameters are the 4 last values of longitudinal level and the cumulative tamping operation from the last 10 years. The analysis consists in identifying the NL evolution which represents the degradation rate of railway track and comparing the maintenance effort to the average for corresponding UIC group.

Maintenance

In these cases taking into account maintenance parameters is a part of a decision making approach which allows confirm the root cause of poor track behaviour [3]. We also focus on the cumulative number of mechanized and manual maintenance.

The analysis' results can help to evaluate the impact of maintenance on the curative work capability to ensure a stable maintenance effort. The parameters 'combination enables to identify railway track portion weaknesses.

Geotechnical Investigations

The maintenance effort of strongly influenced by the properties of the track layers. From the experience and innovative tool we have the opportunities to conduct geotechnical surveys based on combined use of Georadar technique, Panda® dynamic penetration tests and Geoendoscopy [8,5,6]. 2D Georadar evaluations, we obtain a simple representation of the longitudinal section, the ballast fouling, an indication of the moisture content of the ballast and the subsoil. For the Panda® test, in addition to calibrating the Georadar data, we get information about thickness, mechanical quality, moisture condition of the different layers of the railway platform and behaviour of the ballast clogging.

Figure 2 Georadar vehicle (Source: Ground Control Geophysik & Consulting GmbH)

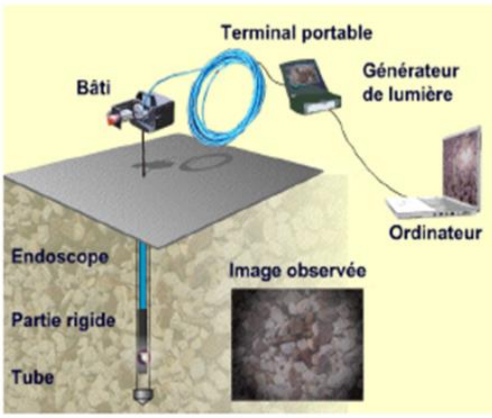

Figure 3 On the left : PANDA® equipment (Source: Sol Solution's PANDA® slides and Benz-Navarrete (2009) [7]) and on the right Geoendoscope (Source: Breul (1999) [11])

We propose to evaluate the following parameters:

- Mechanical quality of the sub ballast layers which is evaluate as a mean value of the cone penetration test (when the information is available),
- Thickness of the sub-ballast layers,
- Mechanical quality of the supporting ground in order respect the SNCF Railway classification (when the information is available),

- Moisture level evaluated by the Georadar or/and Geoendoscopy test [5, 7, 9 ,10]: the presence of water in the different layers degrades the soils mechanical properties so it is essential to evaluate the saturation level.

It is important to note that the rating for each 10m section is based on one-off measures.

Follow-up earthworks and evaluation of drainage capability

The purpose of this analysis is to identify areas with hydraulic hazards with respect to drainage. The identification of vulnerable areas can help to identifying the problem at the source in order to ensure sustainability of the railway track. A second objective is to optimize maintenance and/or renewal work to maintain a healthy line.

The main disorders affecting the track's stability are generally due to poor quality of drainage which plays in important role on the mechanical properties of substructure layers [2]. Under the effect of repeated stress of train circulations and increase in railway load and traffic, trapped waters create progressive and irreversible softening of platforms particularly in sensitive soils (clay, marl, etc.). They contribute rapidly to reduction of lift which is recognized by the alteration of track geometry appearance of muddy areas. Moreover, the geometry of the track can be affected indirectly by alteration and aging of earth structures.

A diagnosis concerning the hydraulic aspect will make it possible to identify the zones with high criticality in order to study them more finely. The parameters chosen for this analysis are as follows:

- Environment of the line (urban, agricultural, forestry) plays an important role on water circulation and consequently on stability of the railway infrastructure,
- Previous water-related disorders are indicative of a risk. This type of disorder and its repetition (within a close perimeter) can give information about a reason related to water. The number of disorder that will be taken into account in this analysis.
- Classification of earth structures according to internal SNCF references, namely sensitive works (OTS) for water-related hazards, special works classified as water-related hazards (OTP) and current structures (OTC),
- Configuration of earthwork: embankment, grading embankment, excavation and more specifically if it is cutting or rock trenches, grazing embankments or simple embankments,
- Drainage and drainage devices with regard to the following criteria :
  - Information on the presence or absence of a water drainage system,
  - Hydraulic and mechanical condition, whether good or bad,
  - Drainage functionality: the drainage of the seating structures must be ensured and there must be no blocking of the flows (no sealed cords, for example). For that purpose, the drainage timing was considered; the top of the drainage must be located lower than the bottom of the intermediate layer, and the presence of rising mud traces.

The evaluation was made for the most critical area of the 10 meters sections and requires an important work of investigations.

2.1.3. The external environment

Geological and hydrogeological analysis

The object of this diagnosis is identifying the zones presenting a geological risk. Geological risk is a hazard that is related to the soils' nature and behaviour. The analysis consists in describing the geological configuration on which the rail network (slope, platform, and track) has been constructed. By defining the different kind of soils (limestone, marl, sandstone ...) identified in the BRGM classification, we can characterize the potential risks that can cause damages to the platform:

- Presence of heterogeneities
- Development of differential movements
- Water stagnation
- Pumping effect
- Appearance of swelling and shrinkage behaviour
- Presence of sinkholes
- Ground subsidence, landslide and gullying hazard

Moreover, flows of water and aquifers circulate through those soils of different natures. Therefore, this analysis is supplemented with an additional approach by identifying the zones presenting a hydrogeological risk with respect to the soils but also with the configuration of the earthwork. Hydrogeological risk is a hazard that is related to groundwater.

The potential presence of an underground water table can lead to indirect or direct disturbances at the level of the platform and track. Phenomena such as muddy ascent, slope slide, and groundwater level variability may result in tracking and / or drainage disorders and flooding of the platform [4]. Two criteria were used to identify potential risk areas thanks to the BRGM classification:

- Groundwater rising risk with the potential presence of an aquifer close to the natural ground level,
- Presence of potential wetlands (marshlands, valleys floors of rivers and other watercourses…)

This geological and hydrogeological diagnosis includes certain limitations such as the data precision, the lack of information and since most of the parameters are not punctual, evaluation was made for the most critical zone of the 10 meters section.

Seismic areas

Depending on the seismic activity degree, earthquakes can deteriorate the network railways. Obviously significant earthquakes can cause a total destruction of the network railway portion but minor ones can also lead platform's damages, engineering structures' and drainage systems' degradation via repeated dynamic vibrations.

Areas of heavy rain

Since 1998, a rainfall monitoring by Météo-France weather radar is carried out on the high-speed line Paris Sud-Est (Paris-Lyon). It consists in emitting warning reports to SNCF traffic control centers when high water levels estimated at line level, following a rainfall, exceed thresholds locally defined as critical. The impacted areas are prone to various disorders in the short and long term.

2.2. Methodology

The main objective of the proposed multidomain analysis is to give an operational guideline for track renewal or rehabilitation. A binary grid which enables us to mark each criterion or degree by 0 or 1 gives risks areas prioritization.

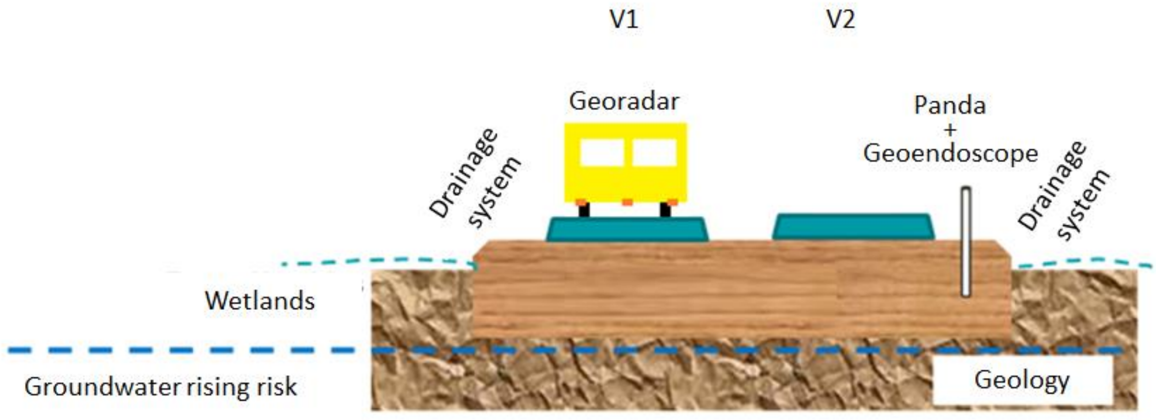

Figure 4 Multidomain approach (Source: SNCF Réseau)

The detection of potential risks areas in the platform requires the crossing of results from environmental criteria accumulation with the track geometry data and more particularly the accumulation of mechanized and manual raw data over ten years.

Eight cases have been set combining the accumulation of environmental parameters and mechanized and manual raw data and a prioritization degree according to the platform mechanical resistance in the short and court term.

For each parameter, the median was calculated to determine the threshold beyond which the risk is considered as relevant.

3. Study case: High-speed line LN1 Paris-Lyon

The following graphs show the results of the evaluation of indicators and the results of complete analysis on track 1 for about 338 km:

Priority	Number of areas (U)	Path accumulation (m)
P1	43	2150
P2	68	3400
P3	238	11900
P4	468	23400
P5	160	8000
P6	393	19650
P7	1897	94850
P8	3500	175000
Total	**6767**	**338350**

Table 1 Risks prioritization of a LN1 338-km portion (Source: SNCF Réseau)

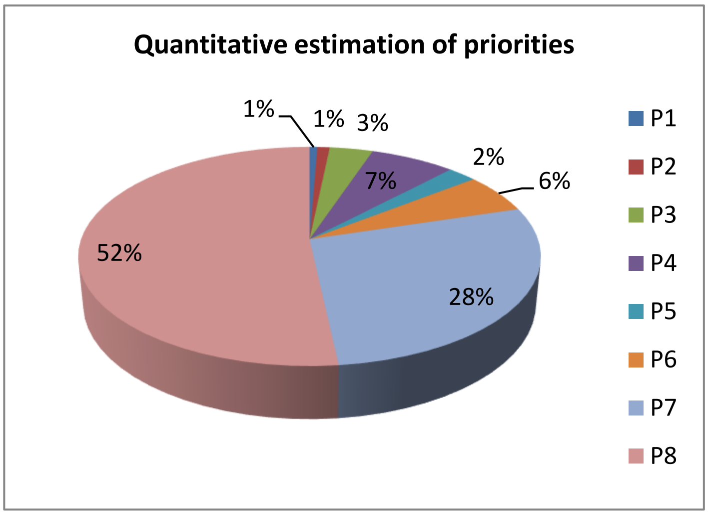

Figure 5 Pie representation of the quantitative estimation of priorities for a LN1 338-km portion (Source: SNCF Réseau)

By cumulating, the four first priority degrees, we can state that 12% of the track require an additional evaluation in order to prepare the potential engineering works such as platform repair work, track and/or ballast replacement or the drainage system replacement.

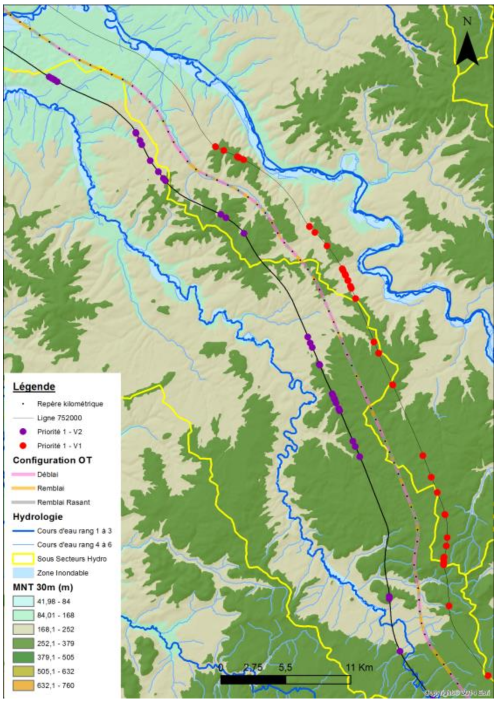

Figure 6 Cartographic representation combining the collected data and the major priority P1 of a LN1 portion for the two main tracks V1 and V2 (Source: SNCF Réseau)

For each critical zone, a summary is written out with refined analyses combining data stated previously. Those summaries help to plan the renewal works.

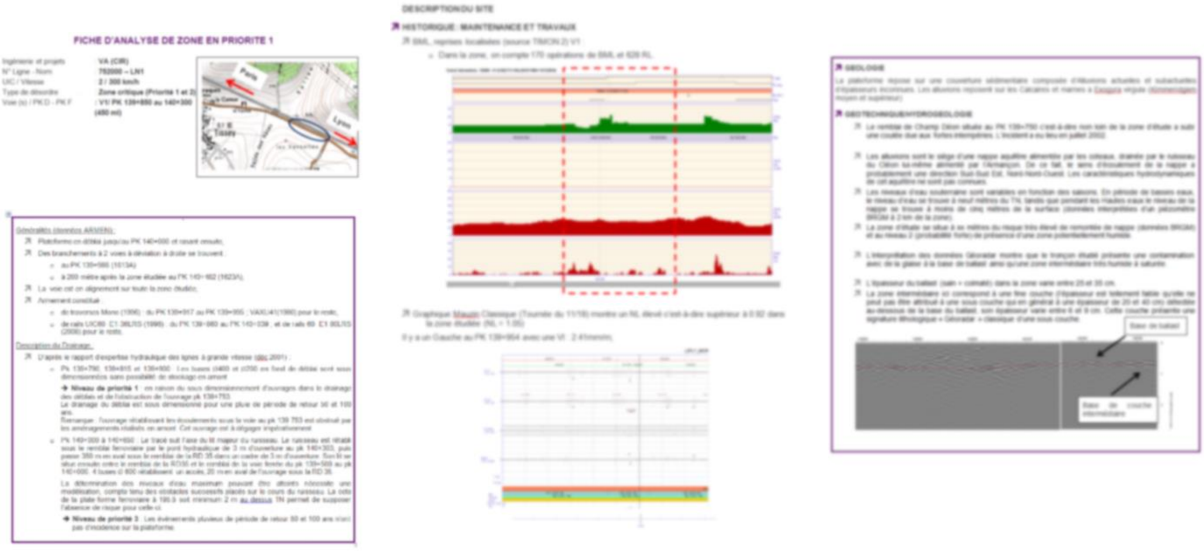

Figure 7 Example of a critical zone summary (Source: SNCF Réseau)

4. CONCLUSIONS

The proposed approach gives a practical framework for engineers by considering 3 domains: the network description, state and the external environment. The combination of those data allows to define directly civil engineering work and gives practical information for railway track manager by evaluate the impact of drainage quality of track performance for example.

Currently the performance of a few part of track renewal need more investigations and analysis to confirm the diagnosis. The railway engineering needs an integrated method to provide a classification of track for choice of maintenance operations. The main difficulty is to establish a curative maintenance management policy appropriate to each type track based on track environment. The main aim of this paper was to present a global framework which allows an evaluation of track portion which need civil engineering work and not only ballast or sleeper or rail replacement.

The next steps of this work consist in extrapolate this method to the other high-speed lines and to develop it from an holistic approach to a predicting model via a Machine Learning algorithm based on expert knowledge and a database composed of numerous diagnosis as presented on this work. This work is ongoing.

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