ABSTRACT
In 2011 INFRABEL decided to invest in W.I.M – Weight-In-Motion monitoring systems. Initially the main focus of the project was the weighting of freight train wagons, load partition on the wagons, and detection and classification of wheel faults.
Soon it was seen that integration of noise emission measurement (TEL) by adding one microphone at 7.5m from the track center and acoustical wheel quality by adding one accelerometer on the rail had more than one advantage. The additional cost of the hardware was minor compared with global cost of an installation (track works, power and ICT-cost), and data captured by weighing sensors could directly be used as an input for the acoustical wheel roughness calculation modules and finally lead to automated real-time processing and estimation of individual wheel roughness data.
All ingredients for such a system were foreseen in the technical requirements of the tender (2011). Today, after soft fine-tuning, validation by means of high speed camera’s, and clear definition of track and site requirements, we are able to count the number of composite (K-LL) or cast iron breaking block running on the Belgian railway network.
The “freight train breaking block retrofit” evolution ongoing in Europe is in Belgium daily monitored.
Keywords: Monitoring, Noise emission,

1. INTRODUCTION
Infrabel, Infrastructure manager of the Belgian railway has to maintain more than 6500km of track and more than 4200 track devices (turnouts,…). Therefore a lot of investments are done in monitoring. Two main monitoring approaches are being used for noise and vibration: monitoring of track acoustical quality by means of an instrumented train using microphones and bearing accelerometers and monitoring of rolling stock by means of fix monitoring stations, who record static and dynamic axle loads, and noise and vibration emission, again by microphones and rail acceleration. Tracks are monitored twice a year and rolling stock will be monitored from 2016 with 7 double track installations toward 15 double track installations by 2020.

2. PROJECT DESCRIPTION
2.1 Initial Requirements
In 2009 the main focus was to measure the total train tonnage, including the individual axle and wheel load, both static and dynamic. The installation of the 15 double track installations should take place in a 3 - 4 year period. We should cover about 90% of the total rolling stock in Belgium, freight and passenger trains.

2.2 Additional requests
The Noise and vibration division of INFRABEL: I-AM.236, responsible for writing the tender of the whole project convinced the project owner to include measurement of the noise emission conform to the ISO 3095 (1), rail acceleration and saving of raw microphone and rail accelerometer data in order to be able to do, in a first stage post-processing, and in a second stage real-time data-analysis towards equivalent wheel roughness. This approached was based on the TNO–Delft (Netherlands Organization for Applied Scientific Research) software PBA (Pass-by analysis) (2)
2.3 Main criteria

The tender, published in 2011 contained following main criteria:

- <30 ton /axle
- Data available after 30s
- 2400 axle/hour
- +/- 5% train weight
- 10% axle loads (30-120km/h)
- Timestamp train identification
- Total train weight + individual detection of vehicle, axle, wheel parameters
- Min. 7 meter measurement area in track
- TEL (transit exposure level) according to ISO 3095 + saving of raw rail acceleration + microphone data
- One year evaluation, 4 calibration tests planned

2.4 Qualification by Calibration train tests

After a selection based on technical specification of 5 bidders, 2 systems were acquired and installed in track on the same line, at a distance of 60m from each other. They were set-up in a standard configuration to measure each train passage on one of the densest points of the network, about 50,000 trains, 90% freight, a year.

Without announcing, test runs were organized, with a specially prepared calibration train. This train consists of 4 two-axle wagons, with a variation of axle loads between 50 and 200 kN, pulled by 2 diesel locomotives, to be able to run in 2 directions on the same track in an efficient way. The calibrated, homologated weights of 5000kg were put out of the center of the wagons to achieve this. The train cars were measured on the very precise static balance weight bridge where precisions better than 1% could be achieved on the individual axle-load measurements.

In order to be able to test the dynamic force several wheel flats were prepared on wheels of the test-train wheels by using limit values described in the EN15313. Finally the acoustical wheel-roughness and out-of-roundness of the individual wheels was measured on μm level in a workshop.

It was surprising to see what a big dispersion was seen when running with the same train several times in both directions at different speeds on both instrumented tracks. One should expect the same tonnage…

2.5 Site requirements for installation of a monitoring system

Selection of the installation sites needs to be studied in detail for several reasons steered both by the weighing and the noise emission part.

2.5.1 Weighing part & general installation

Following aspects should be considered:

- Long term planning of track renewal (to avoid reinstallation in short time)
- Speed restriction possible after placement (until ballast stabilization)
- Possibility to get track out of service / period / ETCS restrictions
- Reference Speed
- Non-braking zone (signaling)
- No slope in track
- Track rigidity (EV2 better then 60Mpa)
- Track composition (rail UIC60E1, sleepers M41, fixation Pandrol clips, stiff EVA rail pad)
- No welding’s, discontinuities in rail
- Out of the stressing zone of the track (at least 150m from dilatation devices)
- Site access to power 3KVA/220V
- Site access to Infrabel INTRAWEB
- Site access for track works

2.5.2 Noise-Vibration emission part

Following aspects should be considered:

- High and stable track decay rate by using dedicated rail pads
- Low and well maintained rail roughness
- Reference track section (ballast/walk pad/concrete bunkers) within regulation with no significant
reflecting objects within 22m around microphones
• No excessing noise emission from other sources (< min. train emission - 15dB)

3. Implementation of TNO PBA-software

3.1 Principle
For details we refer to a website at TNO delft and manuals of the software. https://www.tno.nl/media/2476/pass-byanalysissoftware_tno_81257.pdf
Figure 1 and Figure 2 refer to the used approach in de PBA software.
For calculation of a “Single value indicator for roughness “ we use formula (1) that was suggested in the Harmonoise project (2003) but with some fine tuning in wavelength and contact filters.

\[ L_{\lambda CA} = 10 \log \left( \sum_{\lambda=20 \text{cm}}^{0,4 \text{cm}} 10^{\frac{1}{10}(R(\lambda)+A(\lambda)+C(\lambda)+A(f(\lambda,v)))} \right) \]  

(1)


Figure 1 – Schematic overview of the analysis procedure in PBA software

Figure 2 – Vertical acceleration measurement during four wheel passage
3.2 Classification of roughness

Since we estimate the combined roughness it is clear that the rail always should be below the ISO3095 (1) limit.

- **0 – 4 dB** “smooth rail”
- **5 – 7 dB** “ground rail” (approx. 1 month after grinding)
- **7 – 9 dB** average rail roughness (average of 30 Dutch sites [6])
- **10 – 11 dB** “smooth wheels” (unbraked, disc-braked, or sinter blocks ([6]));
- **12 dB** average rail roughness of the Dutch network in calculation scheme [15];
- **14 – 17 dB** corrugated rail;
- **18 – 20 dB** “rough wheels” (cast-iron blocks, disc+additional cast iron blocks)
- **25 – 28 dB** severe corrugated track

3.3 Implementation in post processing

A first implementation was done by TNO by adapting the standard TNO-PBA-software towards and automated version. It is extremely important to detect with great accuracy the presence of the axle in the timeframe of the acceleration data. (See figure 4: t1, t2, t3, t4). This job was rather easy because the vibration data and the axle presence can be perfectly synchronized by some manufactures of weighting bridges. This leads to a fast estimation of the wheel roughness, not only the Single value indicator, but also the roughness versus wavelength one-third–octave spectra.

Figure 4 and 5 shows the visualization of the rail acceleration with indication of axle presences for a typical freight train passage. In Figure 5 the level of accuracy can easily be seen.

![Figure 4](image-url) Figure 4 – Vertical acceleration and indication of axles

![Figure 5](image-url) Figure 5 – Vertical acceleration and indication of axles zoomed

Figure 6 and 7 shows respectively the one-third–octave spectra wavelengths and the Single value indicator for roughness for the same train passage. Figure 7 clearly shows that some axles are definitely much rougher than other, which was much less obvious in Figure 4.
3.4 Correlation between breaking block and wheel roughness

3.4.1 Validation at standstill

It is well documented that there is a huge difference in wheel roughness based on the type of braking block. (http://uic.org/IMG/pdf/railway_noise_in_europe_2016_final.pdf) A visual inspection is shown in Figure 8. A composite brake block shows a hole in the mounting lip. This is easy at stand still, but for a running train it is more complex. Therefore a high-speed camera campaign was organized.
3.4.2 High speed camera

For several days a high speed camera was installed near the tracks. Figure 9 shows a typical image of a view on the braking blocks of a passed train. It was a huge job to look through all images and note the mounted brake block/axle for hundreds of trains.

Figure 9 – Visual recognition between brake blocks, upper: composite, lower cast iron

3.5 Validation results

This huge amount of data was used to estimate the possibility of detection of the type of brake blocks. Figure 10 shows detailed a validation result for one train passage. In blue dots the Single value indicator for roughness is plotted, while the green dots are representing the high speed camera information: 0 -> recognized composite block, 10 -> recognized cast iron block, 15-> brake block not visual. It is clear that if brake block is visual a very good differentiation (better than 99%) is possible.

Figure 10 – Visual recognition versus Single value indicator for roughness estimate out of rail acceleration
4. Real time implementation

In the future a real time implementation will run on each of the 30 measuring computers in the monitoring network. The type of brake block will then be one of the parameters generated by the system, will be written and become available in XML format on the network server within 30s after the train passage. Tests are ongoing and looking promising. Further validations will be organised by manually measurement of individual wheel roughness and high speed camera’s.

Figure 11 shows a verification plot used within the validation process where we compare in the middle plot the results achieved by TNO (red) and by the INFRABEL (blue) processing routines for a typical freight train with 102 axles. The differences can be understood by the fact that TNO normalises the wheel roughness per bogie which is not done at INFRABEL in order to maximalise info out of the system. The disadvantage can be that a present wheelflat reduces the quality of the roughness estimation. The lower plot classifies the roughness in 4 classes which are represented by dotted lines. In the header of the last graph we see that 22 axles are equipped with composite brake blocks.

Figure 11 – Graphical representation real time processing result / estimation of number of retrofitted axles.
5. Conclusion

The presented approach of estimation of individual wheel roughness by combination of a W.I.M system with N&V monitoring looks promising for the future detection of the by E.C. initiated retrofit of existing freight wagons. Other advantages can be seen, e.g. the % of silent axles can be used as an input for noise mapping according to the European Directive 2002/49/EC. Take into account the correct values will upgrade significantly the quality of each noise mapping project. Also for communication towards citizen, it can be used as a proof that noise emission reduction is evolving in the right direction.

Towards the operators and wagon keepers it can be a stimulator to retrofit their rolling stock and furthermore it opens a possibility to be used to steer NDTAC (Noise Differentiated Track Access Charges) based on real life information. It is the ultimate proof that noise emission and type of brake block are 100% correlated, and finally it can be used to check the acoustic quality of new K and LL brake blocks entering the marked in Europe.

ACKNOWLEDGEMENTS

The author thanks in the first place ir. Jan Mys, former manager of the division Study of Track, and today Head of Singular Assets at INFRABEL, for being charged with this interesting project and the opportunity to work it out from writing of the Tender till implementation, testing, selecting and fine-tuning of the system in the Tracks in all freedom.

Also I want to thank ir. Michaël Dittrich, TNO Delft, being very inspiring and driven in the field of acoustics.

Finally thanks to Dominik Benninghoff, project manager at SCHENCK PROCESS, qualified supplier of the weighing systems in Belgium, and whole the team of SCHENCK for their drive, open mind, and willingness to respond positive on the several requests who are leading, step by step, to very performant and high quality monitoring systems in Belgium.

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