The Fifth International Conference on Railway Technology
RAILWAYS 2022
22–25 August 2022
Montpellier, France

Proceedings of the Fifth International Conference on
Railway Technology:
Research, Development and Maintenance
Edited by J. Pombo
Civil-Comp Conferences, Volume 1, Paper 7.4
Civil-Comp Press, Edinburgh, United Kingdom, 2022, doi: 10.4203/ccc.1.7.4

Towards a Valid Model of Train Braking System at Low Adhesion Condition

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Abstract

The Low Adhesion Braking Dynamic Optimisation for Rolling Stock (LABRADOR) project was a good step towards developing a valid train brake system model to be used to assess the train performance in various adhesion conditions. The LABRADOR model has previously been validated in dry conditions. However, for LABRADOR to become a trusted industry tool then it must be seen to provide accurate predictions of the behaviours of real, contemporary trains that are braking in genuinely low adhesion conditions. Test data from trains braking in low adhesion conditions is rare, but the Rail Safety and Standards Board (RSSB) "T1107 Sander Trial" project has carried out an extensive series of tests in order to measure the brake performance benefits of different sander configurations. Based on the diversity of the data and the number of measured variables in each individual test, the data forms a useful resource for LABRADOR improvement and validation. This paper presents LABRADOR validation process under low adhesion conditions. The sander trial data has been used to develop sanding and cleaning (conditioning) effect models that have been integrated within LABRADOR model. The upgraded LABRADOR model then has been tested and simulated under various low adhesion scenarios that represent the experimental tests. The results shows that the model outputs match the experimental data with a good degree of accuracy.

Keywords: Train Brake system, Wheel Slide Protection (WSP), Train Sanding System, Low adhesion.

1 Introduction

A valid train brake system model is essential to study and assess the train performance in various adhesion conditions. So far, this type of model has not been achieved. The Low Adhesion Braking Dynamic Optimisation for Rolling Stock (LABRADOR) project was a good step towards this objective. However, the lack of test data, specifically under low adhesion conditions prevented the LABRADOR model from being validated. The recent RSSB T1107 sander trial project offers the required data to carry out the validation task. A validated LABRADOR model will provide confidence in the model which will in turn allow industry to study specific brake control features such as wheel slide protection (WSP) strategies, sanding effectiveness, dynamic brake utilisation, traction performance, etc. This understanding will help train operators, maintainers, and integrators to optimise the braking performance of their trains.

The LABRADOR model has been developed to represent the complex behaviour of modern multiple unit passenger trains braking in normal and low adhesion conditions. It is modular to allow easy specification of vehicle, bogie, and wheelset subsystems. Figure 1 shows a block diagram of the LABRADOR model in which the train module interacts with the environment and driver brake demand modules as inputs. The train module contains up to four functionally identical vehicle modules, each vehicle module contains a number of functionally identical wheelset modules. Within the wheelset module, WSP and friction braking, sanding, dynamic braking, and wheel and contact patch subsystems exist. The contact patch module contains the contact patch temperature, contact patch dimension and adhesion creep curve modules. The modular structure of the LABRADOR model provides the easiest way to exploit the duplicated systems within real trains.

The T1107 project undertook full-scale on-track tests, using a modern multiple unit train on representative track, to identify the impact on low adhesion braking performance provided by various combinations of distributed and variable rate sanding. Testing was carried out at Network Rail's RIDC Melton facility. A comprehensive three-month programme of track testing on four and eight car class 387 train yielded 225 individual tests [1].

Based on the diversity of the data and the number of measured variables in each individual test, the data forms a useful resource for LABRADOR improvement and validation.

More information about LABRADOR project can be found in ([2][3]), and about the Sander Trial project can be found in [1].

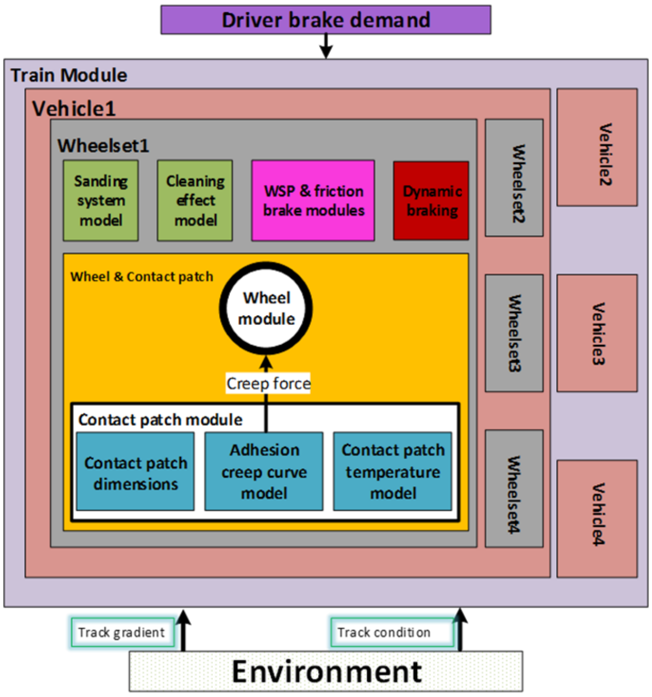

Figure 1: LABRADOR model architecture for 4 car train.

2 Methods

The Sander Trial data was used to develop an improved models for sanders and conditioning effects. For the data processing, the braking runs were grouped together according to the measured initial wheel-rail adhesion and the sanding strategy used. Un-sanded runs were used to calculate the conditioning effect of wheelsets passing over contaminated track and the effect of sand on adhesion was inferred from sanded runs. A statistical analysis was used to derive the mean adhesion profiles from the experimental data. Then, the similar adhesion profiles were modelled using polynomial governing equations according to the following points:

• The runs were grouped together according to similarity of initial wheel-rail adhesion within groups of equal sanding strategy. An attempt was made to cover all the range of low adhesion (0.015-0.08).

• A statistical analysis was performed to determine the average adhesion profile along the train inside each group; the behaviours would then be corrected by comparison with groups with neighbouring adhesion values.

• The first version of the models was extracted from the behaviour of the groups on the corresponding adhesion range. Firstly, the conditioning models were considered, which were discounted from the adhesion profiles to extract the influence of the sanders.

• The models were incorporated in the LABRADOR software (4-car model) and the runs from the Sander Trial were simulated.

• The models were tuned manually to replicate the braking performance achieved with the real train in terms of braking distance and average deceleration.

The assumptions used to create the models are:

- The conditioning effect is constant and always present, and the increase in adhesion saturates after the 10th axle passage (based on statistical analysis of the adhesion profile along the train).
- In the sanding effect model the adhesion increase achieved depends on the initial adhesion, the rate of sand and the number of axles that passed over the sand laid before the axle considered.
- The effect the sand laid by all sanders of the train is the same, except for the first sander. As no sand is considered present on the rail head, the effect of the first layer of sand laid can be different from the following layers.

The wheelsets following the one with the sanding system will also receive some boost in adhesion. This increase decays exponentially with the distance of the wheelsets to the sander; the exponential decay remains constant until the influence of the sand becomes negligible.

3 Results

This section presents a comparison between the experimental data (Sander Trail data) and the simulation results using the upgraded LABRADOR model for different adhesion and sanding scenarios.

Low adhesion non-sanded scenarios

Figure 2 shows the comparison between the simulation model results (crosses) and data from the Sander Trial (dots). For analytical purposes, the data point was grouped according to initial adhesion, the average value for each group is also represented (circles).

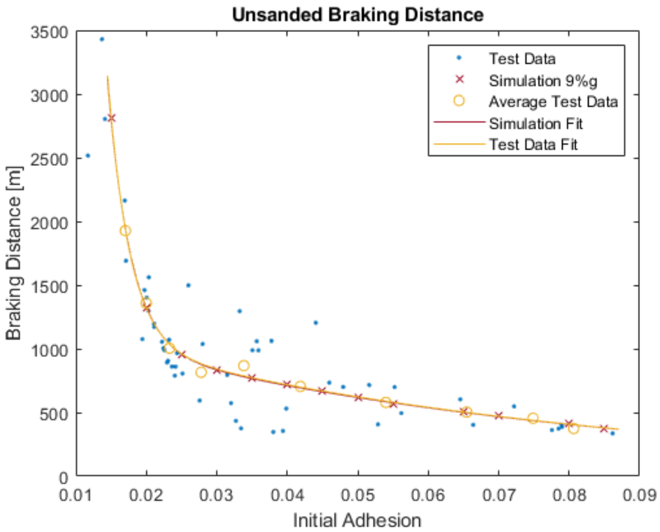

Figure 2 Braking Distance Comparison (non-sanded)

Low adhesion fixed rate sanded scenarios:

The fixed rate sanding scenarios are categorised into two types:

1- **Fixed rate single sander scenarios**, where there is just one sander at the third wheelset. Figure 3 shows the simulation and the experimental results of the stopping distance for this case.

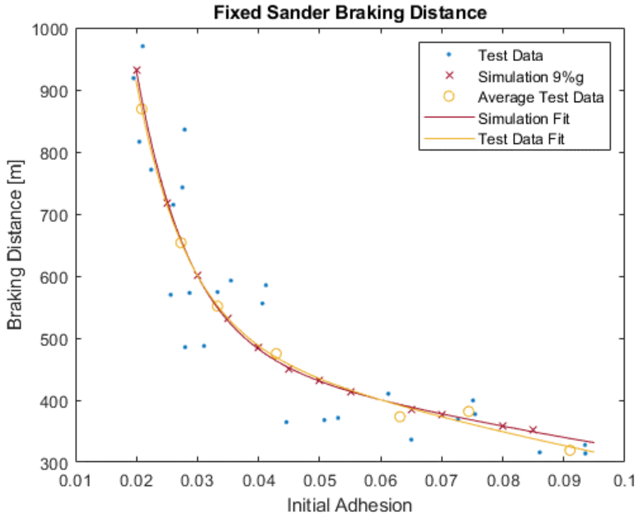

Figure 3 Braking Distance Comparison (fixed rate single Sander)

2- **Fixed rate multiple sanders scenarios**, where the first sander is located at axle 3 and the second at axles 7 or 11. Figure 4 shows the simulation and the experimental results of the stopping distance for this case.

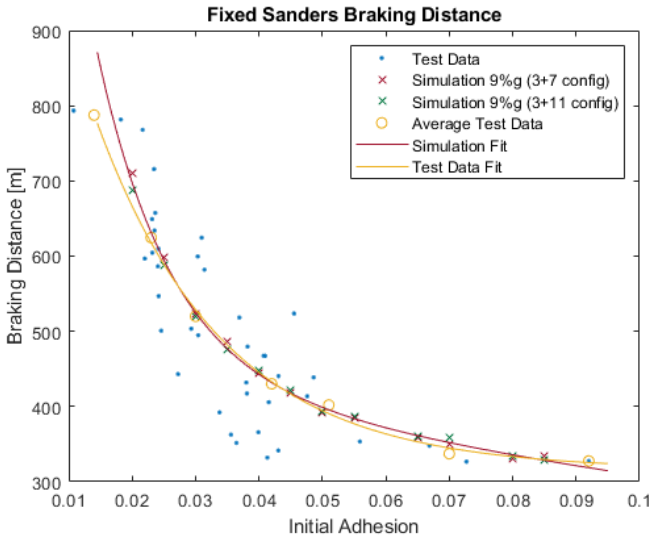

Figure 4 Braking Distance Comparison (fixed rate double Sander)

Low adhesion variable rate sanded scenarios:

There are two sanding configurations in this scenario:

1- **Variable rate single sander configuration**: a single sander on the third axle. Figure 5 shows the simulation and the experimental results of the stopping distance this configuration.

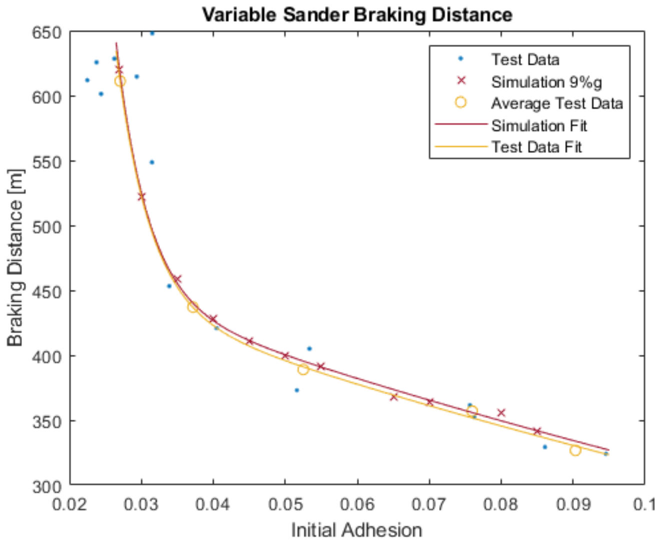

Figure 5 Braking Distance Comparison (Single Sander)

2- **Variable rate double sander configuration:** a double sander in operation, where the first sander is located at axle 3 and the second at axles 7 or 11. The Simulation results and the experimental results of the stopping distance are shown in Figure 6

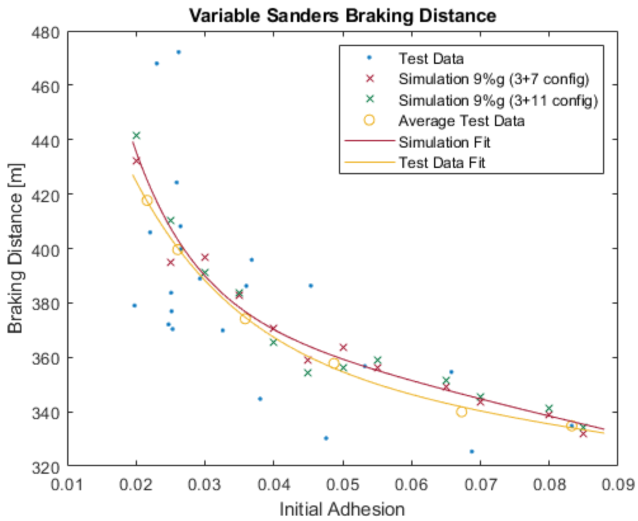

Figure 6 Braking Distance Comparison (Double Sander)

The presented results show that:

- The variability of the data is normally the biggest on the group where the largest accumulation of the data points is concentrated.
- The models created display a good accuracy in estimating the braking distances compared to the Sander Trial data.

The models commonly take a conservative approach and overestimate the braking distance (the train can perform better in real life than simulated).

4 Conclusions and Contributions

The LABRADOR train braking model provides a basis for simulation and assessment of alternative braking system configurations for different trains under varying adhesion profiles and track gradient. The model is configured to preserve the modularity of the various sub-systems within the braking system. Each sub-system is modelled separately in MATLAB/SIMULINK. This approach enables the model to be extended to represent longer trains and each internal module that compose the simulation to be continuously updated and corrected. The Sander Trial enabled the validation of the software in low adhesion, as it was possible to simulate the test runs on the simulation with good accuracy. Some effort is still required to make some of the modules behave according to the reality. However, LABRADOR now allows the study of specific brake control features such as WSP strategies, sanding effectiveness, dynamic brake utilisation, traction performance, etc. This understanding can help train operators, maintainers, and integrators to optimise the braking performance of their trains.

The current version of LABRADOR had the following updates:

- Improved WSP model with reference speed and brake pressure 'hold' function.
- Upgrade of the cleaning / conditioning effect on adhesion module.
- Upgrade of the effect of sanding module.
- Upgrade of the weight transfer module.
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The current model still contains some limitations:

- The vehicle is symmetric (axle loads are equally distributed to each rail);
- The type of brake pad and its characteristics are not taken into consideration.
- The WSP system model represents an older generation of WSP system and only has similar efficiency to modern WSP's (which are not included as their algorithms are proprietary) in some ranges of adhesion.

Acknowledgements

This project has been undertaken as part of the Strategic Partnership between RSSB and the University of Huddersfield. The authors would like to thank the industry members of the project steering group which has provided advice, guidance, and practical support for this project.

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