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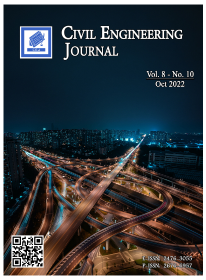

Experimental Measurement and Simulation of Railway Track Irregularities

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Abstract

The study of railway dynamics is still a productive area of research given the rapid technological evolution of this transport system regarding load and speed. Morocco is no exception to this rule, especially after the commissioning of the first high-speed line in Africa. This study describes herein an experiment to measure vertical and transverse accelerations in a locomotive on a railroad line connecting the two cities of Mchraa Ben Abbou and Marrakech. The observed accelerations constitute the vehicle's dynamic responses while running at a constant speed on a track with irregularities (also known as track geometry), which is considered the main driving force of train dynamics and the track system. They are used to evaluate passenger comfort and safety. It can also be observed that body accelerations increase with the introduction of track irregularities as compared to a smoother track. In this study, an analysis of these experimental measurements is performed based on boxplot simulations comparing the distributions of the transverse and vertical components of vehicle acceleration. It was found that the medians and first and third quartiles of both distributions are very close.

Keywords: Track Irregularities; Train-Track Interaction; Railway Line; Vehicle Acceleration.

1. Introduction

High-speed railway (HSR) is a safe, fast, and comfortable transportation mode. In Morocco, the first HSR line was established in 2018 between Tangier and Kenitra, extending over 186 km. Along this line, speed reaches 320 km/h. The high-speed train continues then to Casablanca on a classical rail line with a maximum speed of 160 km/h. Due to HSR's high speed, however, conducting advanced studies in order to control track geometry degradation remains essential, which may lead to increased wheel-rail dynamic interactions and additional track settlement, resulting in additional maintenance costs and poor ride quality [1–3]. Infrastructures for a railway can be of different types: subgrade, tunnels, bridges, or transition zones. The principal differences between these structures are their stiffness and damping. The stiffness of the subgrade is the lowest, and that of a bridge is the highest. These differences cause deviations from the design track geometry, which are called track irregularities (Figure 1).

More generally, track irregularities are caused by subgrade deformation [4–7]. Differential settlements of the soil induce additional bending moments on the rail, causing its deformation. The introduction of continuous welded track also came with the problem of additional stresses in the rails [8-10]. These issues are mainly related to complex interactions between the three system components: subgrade-rail-train. Consequently, higher intensity vibrations are generated inside the vehicle, which alters its safety and comfort. Several numerical models have thus been developed to predict track behavior. El-Moueddeb et al. have developed a finite element track model subjected to the vertical load of the vehicle. The objective of their simulation was to predict mechanical stress in the rail [11].

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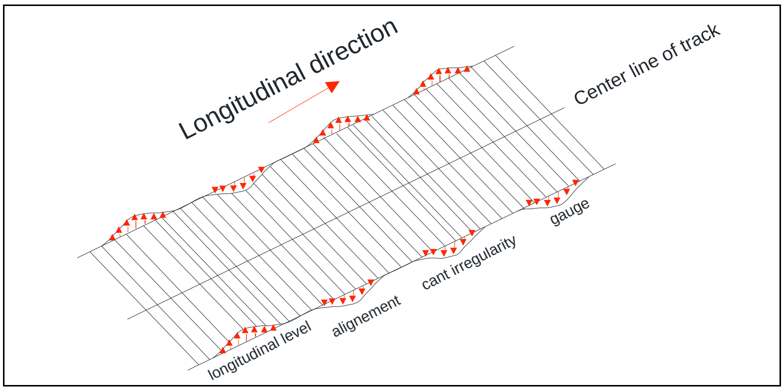

Figure 1. Definition of the fourth types of track irregularities. Longitudinal level; alignment; cant irregularity and gauge

A series of research studies have been conducted to analyze the effects of track irregularities on system component behavior. Several studies used the spring-mass-damper model to analyze and study the noise and vibrations induced by wavelength track irregularities [12, 13]. Other researchers conducted finite element analysis combined with discrete elements to derive the dynamic response of the system [14, 15]. Salcher et al. developed a stochastic process with Monte Carlo simulations to solve the response of the railway bridge in terms of deflection and acceleration [16]. Other researchers proposed hybrid models by combining the simulation of wheel-rail contact force with periodic loss of contact due to track irregularities [17–19].

In order to measure, assess, and simulate track irregularities on the Moroccan railway network, a research study has been conducted with the collaboration of the national Moroccan railway office (NRO). The aim of this study is to implement a process of maintenance able to prevent traffic disruptions and to develop accurate simulations for the dynamic behavior of vehicle-rail-infrastructure interactions.

2. Experimental Measurements of Track Irregularities

Rail traffic stresses the track vertically by static loads presenting the own weight of the vehicles and dynamic loads linked to imperfections of the contact surface Rail/Rail. These imperfections are named track geometry. Considering direct impact of track geometry on traffic safety, the latter benefits from a particular attention in the railway field [20–22]. Geometry measurements must indeed be recorded periodically on Moroccan railway network. Track irregularities were registered in Morocco by a measuring car called EM120. In 2018, for the purpose of this study, vertical and transverse accelerations inside a track car (EM120) have been recorded along 114 Km of railway line linking Casablanca to Marrakech (242 Km). The recordings started from Marrakech (Latitude 31° 32' N & Longitude 8° 1' W) and ended at Mechrâa Ben Abbou (Latitude 32° 39' N & Longitude 7° 47' W), (see Figure 2).

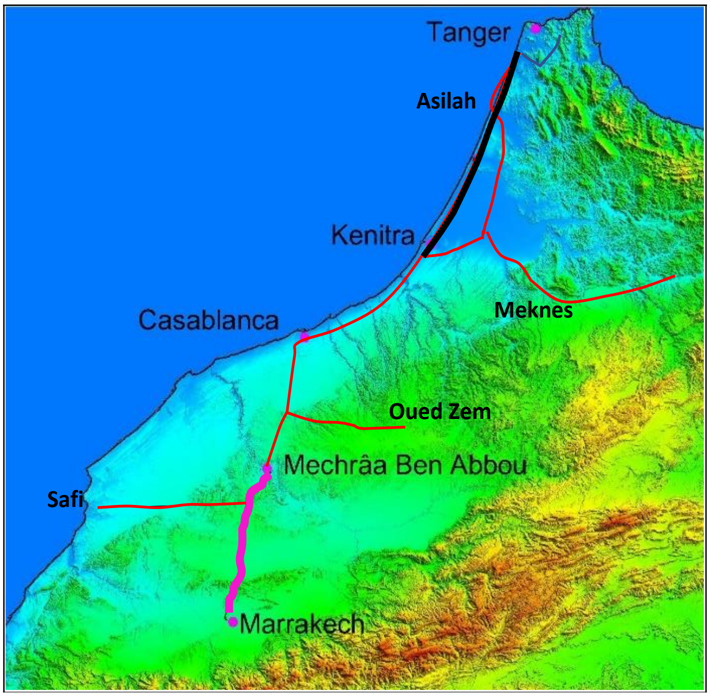

Figure 2. Map of the Moroccan railway network. The black line is the HSR line linking Tanger to Kenitra, the red lines are the classical network and the pink line is where measurements were recorded

The measurements were made at regular intervals with a 0.005 s time step, while track car speed was maintained equal to 100 km/h. The measurements were undertaken by mounting accelerometer devices on the axle boxes, bogie frames and in car bodies (Figures 3 and 4). The devices included data acquisition, processing system and a GPS receiver for monitoring and recording speed of the vehicle. A total of two million measured values of both transverse and vertical accelerations were available at the end of the operation.

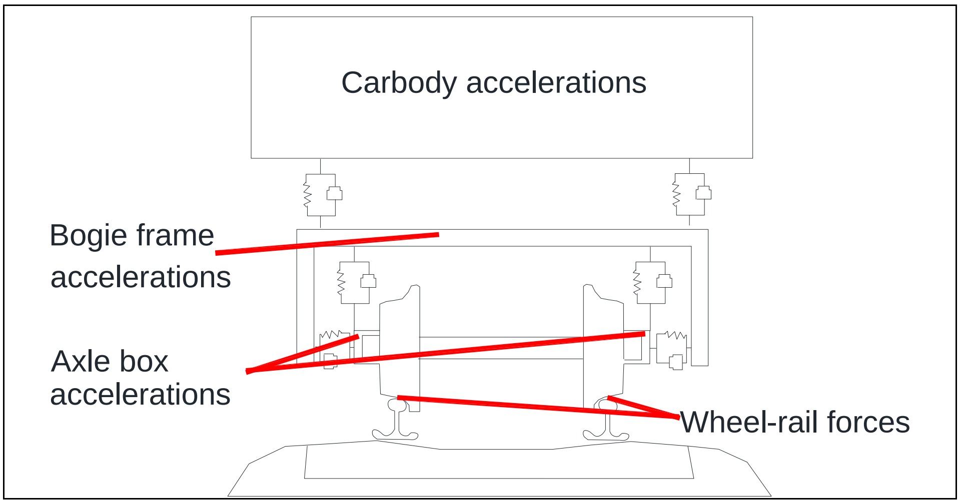

Figure 3. Accelerometer devices mounted on the axle boxes, bogie frames and in the car bodies

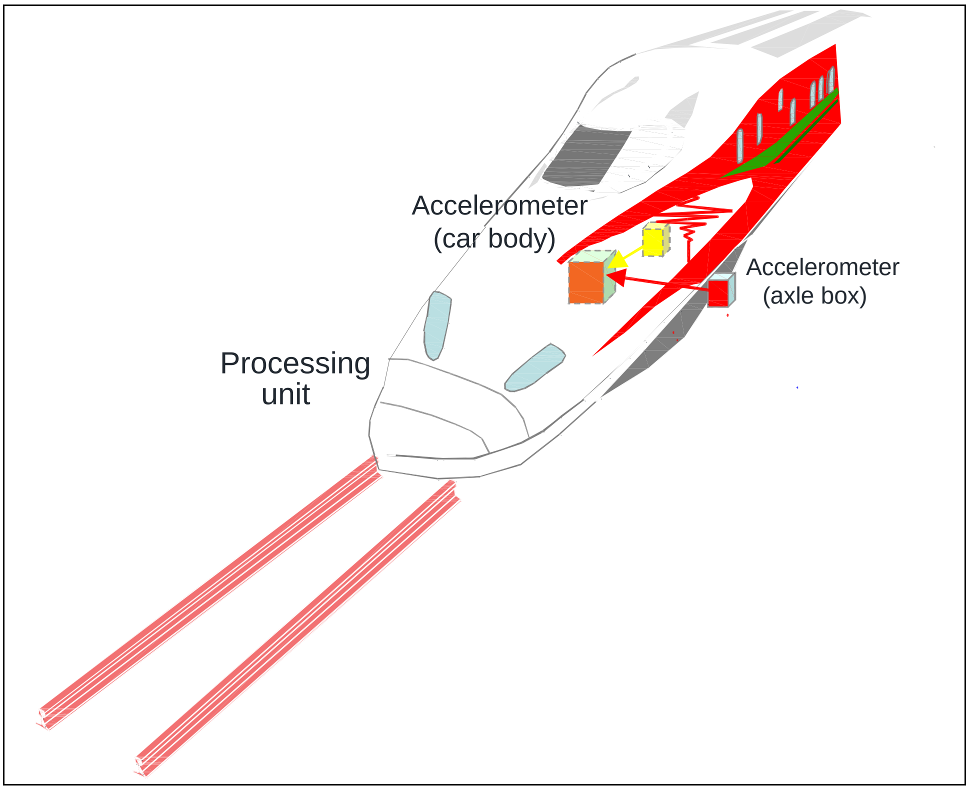

Figure 4. Axle box and car body accelerations recorded onboard EM120

These measurements were then analyzed through the use of boxplots. Firstly, boxplots of acceleration along each direction were examined. This step allows to investigate if distortion is preserved for the two distributions. According to the obtained results, a correlation between these distributions can be formulated, based on the fact that these are components of one resultant acceleration. Hence, atypical values of acceleration can be obtained by using the boxplot of the correlated distribution. For the purpose of dealing with large resulted data, it is appropriate to adopt a process to extract well defined sections from the obtained points. The process here consists of determining the distances between all consecutive points of the set. Finally, this research methodology will lead to the geolocalization of atypical sections. These are the critical zones that need specific investigations to examine the origins behind the abnormal behavior of the train-track-foundation system (Figure 5).

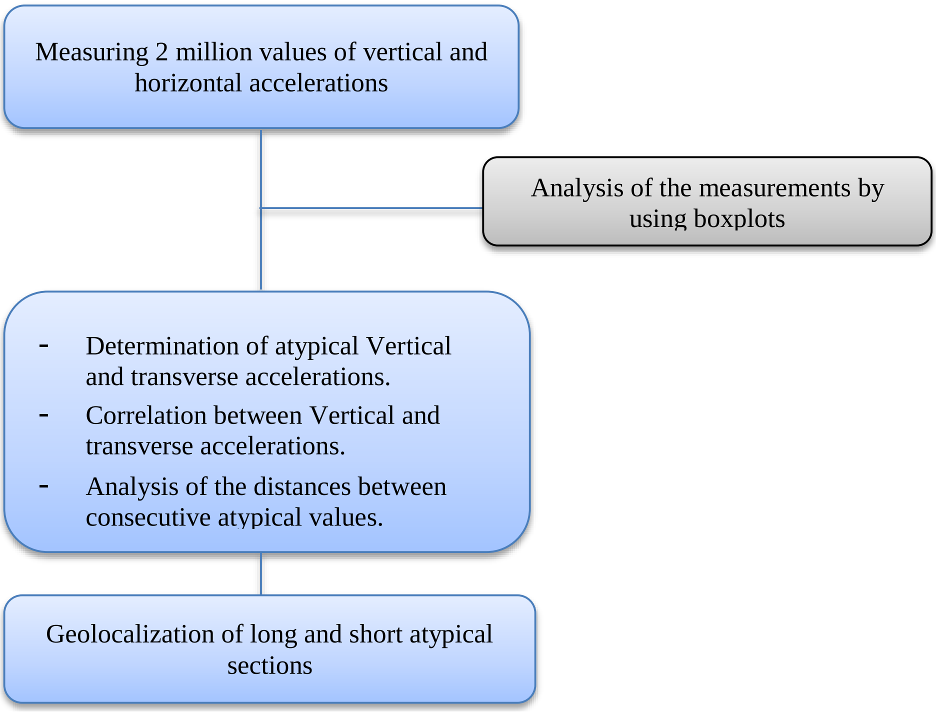

Figure 5. Flowchart for the research methodology

3. Transverse and Vertical Accelerations

In order to compare between the distributions for random variables representing transverse and vertical accelerations, two boxplots are displayed in Figure 6. The one on the left side of the figure (blue color) describes transverse acceleration, while the other on the left side (orange color) illustrates vertical acceleration.

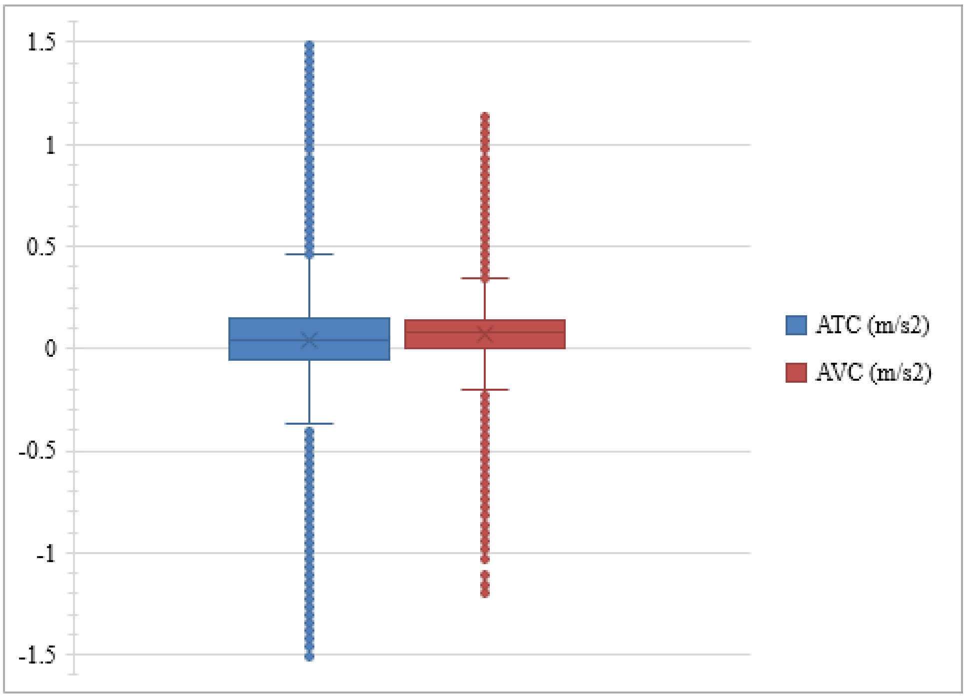

Figure 6. Two boxplots illustrate transverse and vertical acceleration distribution. For each acceleration component, one million measured values are represented

Differences between transverse and vertical distributions are shown on Figure 7 as follows:

The median for transverse acceleration is 0.04 m/s^2; the first and third quartiles Q1 and Q3 are respectively 0.05 and 0.15 m/s^2. 106 thousand outliners were located below lower border (-0.37 m/s^2) while 100 thousand values are above upper border (0.46 m/s^2). On another hand, the median in the vertical acceleration distribution was 0.07 m/s^2. The first quartile Q1 and the third Q3 were respectively 0.00 and 0.14 m/s^2. 27 thousand outliners were below lower border (-0.2 m/s^2) while 23 thousand values were above upper border (0.34 m/s^2). The medians, first and third quartiles of both distributions were surprisingly very close. The results also indicates that no distortion is registered. It has also been observed that the inter quartile range was slightly more spread out for vertical acceleration distribution (0.14 m/s^2) compared than the one of transverse acceleration (0.10 m/s^2).

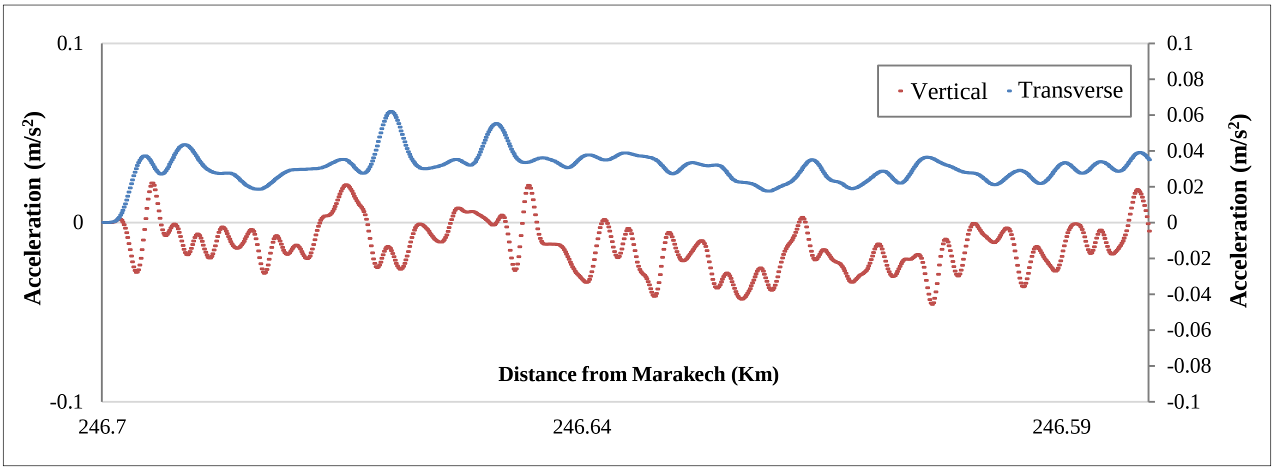

Figure 7. Extract from transverse and vertical accelerations recorded along the railway line linking Marrakech to Mechrâa Ben Abbou

In order to overcome the absence of distortion between the vertical and transverse accelerations, a single distribution should be composed from the previous ones, since they are the components of the resultant acceleration. It is obvious that a correlation can be obtained by the sum of the squares of each component. This correlation can be written as follows: ${a_T}^2 = ATC^2 + AVC^2$. Hence, a boxplot can be drawn for the distribution formed by using this correlation as shown in (Figure 8).

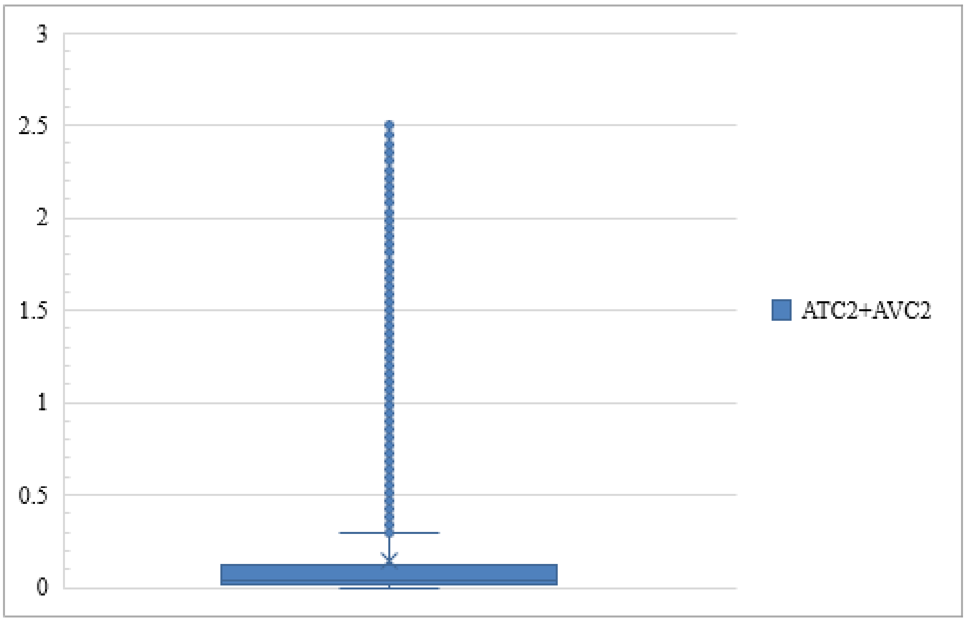

Figure 8. Boxplot displaying the distribution formed by using a correlation between vertical and transverse measured accelerations

From Figure 8, it can be observed that this approach has led to the recognition of a total of 98,000 atypical points, with a value equal to 0.3 m/s^2, located between Marrakech and Mechrâa Ben Abbou. This is a large, granular set of points that still doesn't show clear information. It is why an appropriate treatment is needed again to extract well-defined sections from this big data. The treatment consists of determining the distances between all consecutive points of the set, which have been found to be almost zero, and have conducted to make a distinction between short and long sections. Finally, 126 atypical sections of a total length of 19.3 km were delimited. Among these segments, 8 long sections with a medium length of 954 m and 118 short sections with a medium length of 108 m were revealed (Figures 9 and 10).

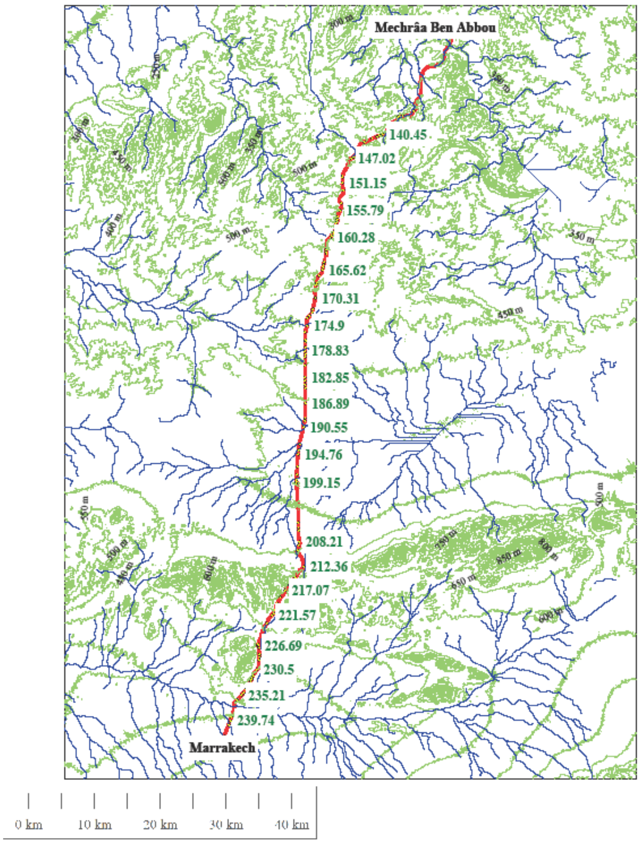

Figure 9. Geolocalization of 118 short critical section on the railway line between Marrakech and Mechrâa Ben Abbou. These sections are denoted by the distance in kilometers from Casablanca

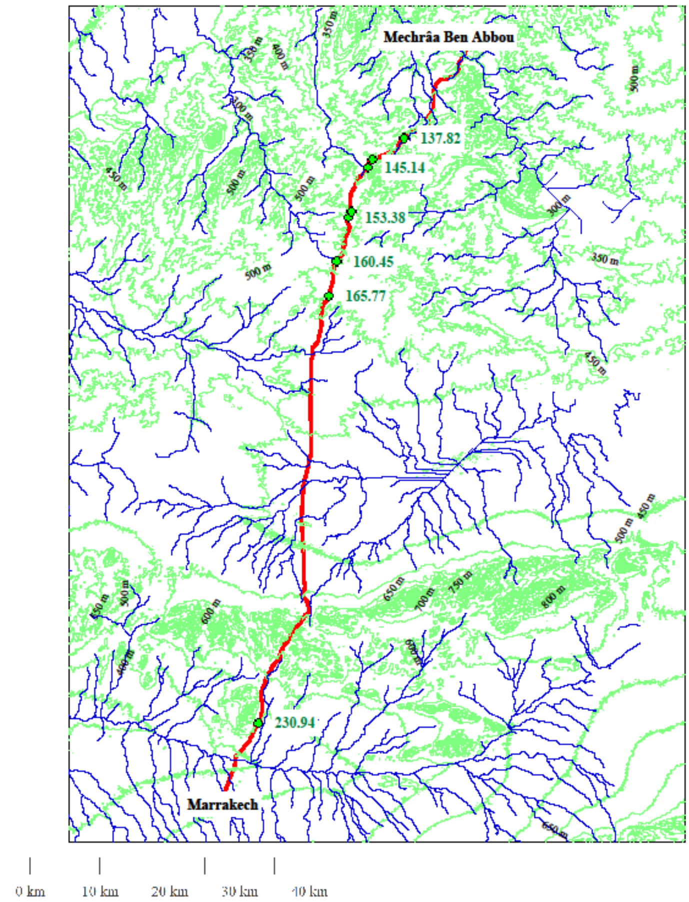

Figure 10. Geolocalization of 8 long critical section on the railway line between Marrakech and Mechrâa Ben Abbou. These sections are denoted by the distance in kilometers from Casablanca

4. Conclusion

Assessment and simulation of track irregularities on the Moroccan railway network have been elaborated in this study. This investigation was based on vertical and transverse acceleration measurements. These components were recorded inside a track car (EM120) along 114 km of the railway line linking Casablanca to Marrakech. Using boxplot simulations for transverse and vertical acceleration showed that the medians, first and third quartiles of both distributions were very close. It also indicated that there was no distortion between both distributions. Examination of the logical correlation between these measurements combined with the analysis of the distances between atypical values led to the geolocalization of 126 critical zones requiring further investigations for the possible sources of irregular behavior.

5. Declarations

5.1. Author Contributions

Conceptualization, L.B., N.L. and F.K.; methodology, L.B., N.L. and F.K.; software, L.B., and F.K.; validation, N.L. and F.K.; formal analysis, L.B., N.L. and F.K.; investigation, L.B., N.L. and F.K.; resources, L.B., N.L. and F.K.; data curation, L.B. and F.K.; writing—original draft preparation, L.B. and F.K.; writing—review and editing, L.B., and F.K.; visualization, N.L.; supervision, N.L.; project administration, N.L.; funding acquisition, L.B. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

Data sharing is not applicable to this article.

5.3. Funding

The authors received no financial support for the research, authorship, and publication of this article.

5.4. Conflicts of Interest

The authors declare no conflict of interest.

6. References

[1] Malveiro, J., Sousa, C., Ribeiro, D., & Calçada, R. (2018). Impact of track irregularities and damping on the fatigue damage of a railway bridge deck slab. Structure and Infrastructure Engineering, 14(9), 1257–1268. doi:10.1080/15732479.2017.1418010.

[2] Xu, L., Li, Z., Zhao, Y., Yu, Z., & Wang, K. (2022). Modelling of vehicle-track related dynamics: a development of multi-finite-element coupling method and multi-time-step solution method. Vehicle System Dynamics, 60(4), 1097–1124. doi:10.1080/00423114.2020.1847298.

[3] Pecile, B. (2017). Dynamic model of vehicle-railway interaction in the presence of geometric defects on the surfaces in contact. PhD Thesis, University of Valenciennes and Hainaut-Cambresis, Valenciennes, France. (In French).

[4] Haigermoser, A., Luber, B., Rauh, J., & Gräfe, G. (2015). Road and track irregularities: Measurement, assessment and simulation. Vehicle System Dynamics, 53(7), 878–957. doi:10.1080/00423114.2015.1037312.

[5] Nielsen, J. C. O., & Li, X. (2018). Railway track geometry degradation due to differential settlement of ballast/subgrade – Numerical prediction by an iterative procedure. Journal of Sound and Vibration, 412, 441–456. doi:10.1016/j.jsv.2017.10.005.

[6] Kassou, F., Benbouziyane, J., Ghafiri, A., & Sabihi, A. (2021). A New Approach to Analyse the Consolidation of Soft Soils Improved by Vertical Drains and Submitted to Progressive Loading. KSCE Journal of Civil Engineering, 25(1), 51–59. doi:10.1007/s12205-020-0060-z.

[7] Lamprea-Pineda, A. C., Connolly, D. P., & Hussein, M. F. M. (2022). Beams on elastic foundations – A review of railway applications and solutions. Transportation Geotechnics, 33, 100696. doi:10.1016/j.trgeo.2021.100696.

[8] Blanco-Saura, A. E., Velarte-González, J. L., Ribes-Llario, F., & Real-Herráiz, J. I. (2018). Study of the dynamic vehicle-track interaction in a railway turnout. Multibody System Dynamics, 43(1), 21–36. doi:10.1007/s11044-017-9579-2.

[9] Kukulski, J., Gołębiowski, P., Makowski, J., Jacyna-Gołda, I., & Żak, J. (2021). Effective method for diagnosing continuous welded track condition based on experimental research. Energies, 14(10). doi:10.3390/en14102889.

[10] Skarova, A., Harkness, J., Keillor, M., Milne, D., & Powrie, W. (2022). Review of factors affecting stress-free temperature in the continuous welded rail track. Energy Reports, 8, 769–775. doi:10.1016/j.egyr.2022.05.046.

[11] El Moueddeb, M., Louf, F., Boucard, P. A., Dadié, F., Saussine, G., & Sorrentino, D. (2020). A lightweight numerical model of railway track to predict mechanical stress state in the rail. International Journal of Transport Development and Integration, 4(2), 152–162. doi:10.2495/TDI-V4-N2-152-162.

[12] Groß-Thebing, A., Knothe, K., & Hempelmann, K. (1992). Wheel-Rail contact mechanics for short wavelengths rail irregularities. Vehicle System Dynamics, 20(Sup1), 210–224. doi:10.1080/00423119208969399.

[13] Kedia, N. K., Kumar, A., & Singh, Y. (2021). Effect of Rail Irregularities and Rail Pad on Track Vibration and Noise. KSCE Journal of Civil Engineering, 25(4), 1341–1352. doi:10.1007/s12205-021-1345-6.

[14] Kouroussis, G., Gazetas, G., Anastasopoulos, I., Conti, C., & Verlinden, O. (2011). Discrete modelling of vertical track-soil coupling for vehicle-track dynamics. Soil Dynamics and Earthquake Engineering, 31(12), 1711–1723. doi:10.1016/j.soildyn.2011.07.007.

[15] Bogdevičius, M., Žygiene, R., Dailydka, S., Bartulis, V., Skrickij, V., & Pukalskas, S. (2015). The dynamic behaviour of a wheel flat of a railway vehicle and rail irregularities. Transport, 30(2), 217–232. doi:10.3846/16484142.2015.1051108.

[16] Salcher, P., Adam, C., & Kuisle, A. (2019). A Stochastic View on the Effect of Random Rail Irregularities on Railway Bridge Vibrations. Structure and Infrastructure Engineering, 15(12), 1649–1664. doi:10.1080/15732479.2019.1640748.

[17] Nielsen, J. C. O., Lombaert, G., & François, S. (2015). A hybrid model for prediction of ground-borne vibration due to discrete wheel/rail irregularities. Journal of Sound and Vibration, 345, 103–120. doi:10.1016/j.jsv.2015.01.021.

[18] Soyiç Leblebici, A., & Türkay, S. (2017). Influence of Wheel-Rail Contact Stiffness on the H2 Controlled Active Suspension Design. IFAC-PapersOnLine, 50(1), 3642–3647. doi:10.1016/j.ifacol.2017.08.710.

[19] Zhang, X., Thompson, D., & Sheng, X. (2020). Differences between Euler-Bernoulli and Timoshenko beam formulations for calculating the effects of moving loads on a periodically supported beam. Journal of Sound and Vibration, 481, 115432. doi:10.1016/j.jsv.2020.115432.

[20] Martínez-Casas, J., Giner-Navarro, J., Baeza, L., & Denia, F. D. (2017). Improved railway wheelset–track interaction model in the high-frequency domain. Journal of Computational and Applied Mathematics, 309, 642–653. doi:10.1016/j.cam.2016.04.034.

[21] Xu, L., Chen, X., Li, X., & He, X. (2018). Development of a railway wagon-track interaction model: Case studies on excited tracks. Mechanical Systems and Signal Processing, 100, 877–898. doi:10.1016/j.ymssp.2017.08.008.

[22] Guo, Y., & Zhai, W. (2018). Long-term prediction of track geometry degradation in high-speed vehicle–ballastless track system due to differential subgrade settlement. Soil Dynamics and Earthquake Engineering, 113, 1–11. doi:10.1016/j.soildyn.2018.05.024.