

# A Study of Impact of Wheel and Track Wear on Train Swaying

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## Abstract

This study looks into the effect of wheel and track wear on train swaying, which impacts travel comfort and operational safety. The goal was to identify essential variables—such as track shape, wheel flange wear, suspension dynamics, and operational speed—and evaluate their relationship to swaying severity. Swaying levels were quantitatively assessed using Xsens Motion Tracker sensors in a mixed-methods approach that included a literature analysis, expert consultation, historical data from regular service trains, and unscheduled high-speed field testing on Express Train X1-07. Before the first wheel reprofiling (WP1), results revealed that swaying levels decreased from 0.58 m/s<sup>2</sup> to 0.38 m/s<sup>2</sup>, mostly owing to a drop in speed. After WP1, swaying reached a peak of 0.54 m/s<sup>2</sup> before decreasing, while WP2 saw little improvement, with values increasing from 0.45 to 0.52 m/s<sup>2</sup>. Unscheduled tests at steady speeds (140-145 km/h) revealed swaying levels ranging from 0.49 to 0.63 m/s<sup>2</sup>, with Track 2 showing more instability than Track 3. These data demonstrate that wheel profiling alone is insufficient unless it is combined with speed control and improved track condition management. As a recommendation, the study suggests using updated measurement equipment, streamlining personnel involvement to improve data consistency, improving interdepartmental collaboration, and enforcing quality control in maintenance procedures—all of which aim to reduce swaying, improve passenger comfort, and extend asset lifespan across railway systems.

## 1. Introduction

The car body sway refers to the lateral, yaw, or roll motion of railway vehicles along the track and is typical in high-speed trains, passenger cars, metro vehicles, and locomotives. This phenomenon can cause discomfort for passengers and wear on both the train and track. Among the factors that contribute to the car body sway behaviour are hunting motions, aerodynamic effects, track irregularities, and centrifugal forces during curve negotiation. Uneven wear of rails always occurs on opposite sides with specific intervals in tangent or large-radius curved tracks. Train sway, which is characterized by lateral oscillations of the vehicle body, is a prevalent issue in railway operations, as it can lead to passenger discomfort, reduced ride quality, and, in severe cases, derailments. By understanding the factors influencing train sway, railway engineers and operators can implement necessary measures to control and mitigate its effects. The behaviour of train sway is a critical consideration in railway engineering, as it can significantly impact ride comfort levels, operational safety, and

the lifespan of rail infrastructure. This report aims to provide a comprehensive analysis of the key variables that influence train swaying to initiate the development of a more robust and reliable railway system.

## 1.1 Problem Statement

Despite considerable advancements in railway technology, the issue of train sway persists as a significant challenge. The intricate interplay of various factors—including track irregularities, vehicle dynamics, and operational conditions—complicates the accurate prediction and management of train sway. Excessive train swaying can reduce passenger comfort and in extreme instances, an elevated risk of derailment. Therefore, understanding the contributing factors is essential for enhancing the safety and efficiency of railway transportation. Recently, passengers on the railway line between Kuala Lumpur city and the airport have reported that the train is experiencing severe swaying movements when using the train service. For the authorities involved, rectifying the swaying issue can pose a unique challenge, especially when the railway system has different authorities overseeing different sections. There is a company that is responsible for the maintenance of the railway track, another company for the operation and maintenance of the railway fleets, and a company involved with customer service and overseeing the companies in the railway system. This intricate structure can be an issue when there are rectifications that need to be made, and with different companies having different types of data at their disposal, efficient communications and coordination are necessary to combat train sway. Therefore, to address this problem, a study was conducted to examine the critical factors that contribute to train sway, which then the data based on the findings of the previous tests and one-off tests were analyzed to examine how the variables explain the severity of train swaying, and to come up with suitable strategies and design improvements that can enhance passenger comfort and satisfaction while mitigating the severity of train sway.

## 1.2 Objectives

The primary objective of this study is to

- To identify the key factors influencing train sway such as track irregularities, train speed, suspension systems, and aerodynamic forces.
- To analyze the relationship between identified variables and train swaying dynamics by performing data analysis on the findings from the conducted tests.
- To propose recommendations for improving train swaying measurement approaches to ensure the consistency and accuracy of the measurement data.

## 1.3 Scope and Significance of Study

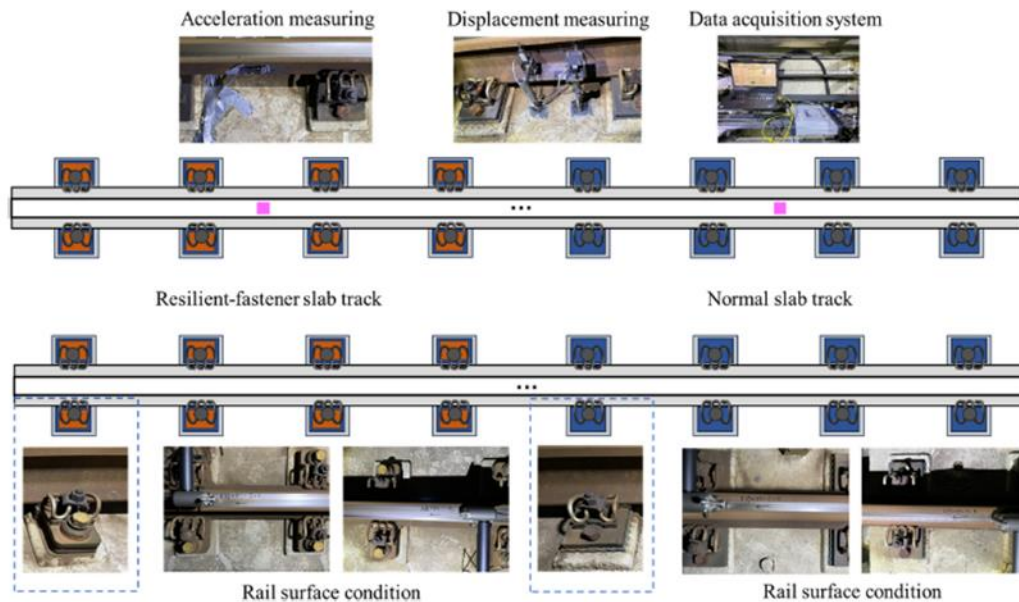
This study focuses on identifying and analysing the key variables that impact train swaying behaviour, with particular emphasis on the following aspects:

- **Track geometry**, including alignment errors, surface defects, and other irregularities that can induce lateral forces on the train.
- **Vehicle dynamics**, such as mass distribution, suspension stiffness, and damping characteristics, which influence the train's response to track irregularities. (Majka & Hartnett, 2009)
- **Operational parameters**, including train speed, braking, and acceleration, can contribute to the development of swaying motion.
- **Environmental conditions**, such as wind loads and temperature variations, can exert external forces on the train and affect its dynamic behaviour.
- The study will involve a combination of field measurements and calculations to quantify the severity of train sway.
- The findings of this study will contribute to developing more robust and reliable railway systems, with improved passenger comfort and safety, as well as reduced maintenance costs for infrastructure.

The findings of this study will have substantial implications for the design, maintenance, and operation of railway systems. By acquiring a comprehensive understanding of the variables affecting train sway, railway engineers and operators will be better equipped to optimize vehicle design and suspension parameters. This optimization is intended to reduce sway, thereby enhancing passenger comfort and ensuring safe and efficient railway operations. Furthermore, the study will support the development of targeted track maintenance strategies aimed at addressing specific irregularities that contribute to swaying behaviour. By implementing these strategies, the industry can effectively mitigate the factors leading to train sway and improve overall train stability. Ultimately, railway operators will be able to establish operational protocols that manage train speed and braking, thereby reducing the risk of sway-related incidents and reinforcing the safety and reliability of train operations.

## 2. Literature Review

Train swaying, characterized by lateral oscillations of the vehicle body, remains a critical concern in railway operations due to its impact on passenger comfort, safety, and infrastructure longevity. Numerous studies have identified track geometry as a primary contributor, where alignment errors, surface defects, and rail wear induce vertical and lateral forces that exacerbate sway [1][2][3]. These irregularities transmit vibrations through the vehicle-track system, often intensified by deteriorating track conditions and insufficient vibration attenuation mechanisms [4].



**Fig.1** Schematic diagram of vibration testing of different track structures

Vehicle dynamics further compound the issue, with factors such as mass distribution, suspension stiffness, and damping characteristics influencing the train's response to track anomalies [5][6][7]. Operational parameters, including speed and braking, also play a pivotal role, especially under crosswind conditions where aerodynamic forces can destabilize the train [8], [9]. Environmental influences like wind gusts and temperature fluctuations affect wheel-rail interactions, contributing to abnormal lateral vibrations [10], [11]. Passenger comfort standards, particularly those outlined in ISO 2631, underscore the complexity of evaluating whole-body vibration (WBV), with studies revealing that discomfort is influenced not only by vibration exposure but also by individual variability and environmental context [12][13][14][15]. Collectively, these findings highlight the multifactorial nature of train sway, emphasizing the need for integrated maintenance strategies, optimized suspension systems, and refined operational protocols to enhance ride stability and passenger satisfaction.

## 3. Methodology

This study uses a structured technique to gather and analyze data in order to assess the impact of wheel and track wear on train swaying. The purpose is to better understand how variables like wheel quality, track design, and operational speed affect swaying levels, particularly in express rail systems. To accomplish this, the system combines qualitative insights from expert discussions with quantitative data from historical records and field measurements. By basing the analysis on real-world operational data and technical concepts, this study ensures that its conclusions are accurate and relevant to the railway sector.

### 3.1 Strategy

The study used a multi-phase data analysis technique to investigate the association between wear metrics and train swaying. First, major contributing parameters were discovered through literature reviews and expert contacts, with track imperfections, wheel flange dimensions, suspension performance, and train speed being the principal variables. The components were then divided into three categories: track geometry, vehicle characteristics, and operating parameters. Historical information from the maintenance department's cloud database, featuring swaying readings for trains over a two-year period, were used to demonstrate the data collection procedure. The dataset measured swaying levels ( $m/s^2$ ), wheel flange height and thickness (mm), and operational speed (km/h) at consistent track checkpoints. In addition, unannounced testing was carried out

with the Xsens MTi-100 Motion Tracker mounted within the driver's cab. To isolate the effect of track shape and speed variation, these experiments were done on express train X1-07 at constant speeds (140 km/h and 145 km/h) across two tracks—Track 2 and Track 3.



**Fig. 4** Train Swaying Measurement tools (a) The sensor used (b) Measurement Process from Software

The use of synchronized real-time monitoring with XSens MT Manager software allowed for lateral acceleration logging, which help with the dependability of the results. The data were analyzed to better understand how the independent factors influenced swaying dynamics over time and in regulated speed situations. Visualizations like as line graphs and swaying profiles aided in the detection of performance irregularities and the assessment of wheel-track interactions. Measurements were plotted to identify patterns in swaying severity before and after wheel reprofiling events (WP1 and WP2), as well as to compare performance at various speeds and track conditions.

#### 4. Result

The study aimed to evaluate the severity of train swaying through historical and experimental data, focusing on the Express system. Historical data from train X1-01 at KM52.5 in Figure 1 (a) revealed fluctuations in swaying levels over time, with values ranging from 0.35 to 0.58  $m/s^2$ . These were correlated with wheel flange height and thickness, and operational speed. For example, after wheel profiling (WP1 and WP2), swaying levels did not consistently decrease, suggesting complex interactions between wheel condition and track geometry. In unscheduled tests using train X1-07, swaying levels were measured at constant speeds of 140 km/h and 145 km/h across multiple checkpoints, as shown in Table 1 and Figure 1 (b). The results showed that higher speeds generally led to increased swaying, with peak values reaching 0.63  $m/s^2$ . These findings were visualized through graphs and tables, highlighting the variability in swaying patterns across different operational conditions.

**Table 1:** Test Result Data of X1-07

Location (KM)	52.5	49	40.7	37.7	36	33	26.5
145 km/h (1)	0.61	0.60	0.57	0.51	0.60	0.54	0.53
145 km/h (2)	0.49	0.62	0.60	0.62	0.59	0.63	0.61
140 km/h (1)	0.54	0.51	0.55	0.55	0.53	0.51	0.52
140 km/h (2)	0.55	0.52	0.56	0.54	0.51	0.52	0.53

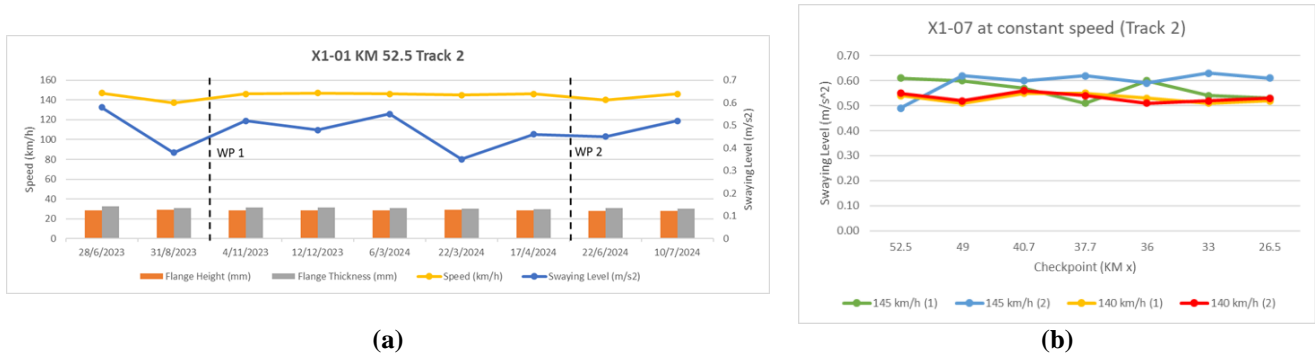


Fig. 4 Train Data (a) X1-01 Historical Data; (b) X1-07 Test Result

### 4.1 Discussion

The data analysis revealed inconsistencies in swaying severity, even after maintenance interventions such as wheel profiling. This suggests that swaying is influenced by multiple factors beyond wheel condition alone. One major issue identified from the analysis was the inconsistency and incompleteness of available data, which hindered accurate trend analysis. Additionally, the lack of integrated data between track and rolling stock maintenance teams posed challenges in correlating wheel and track conditions. The study also noted that different train systems have varying operational profiles, affecting swaying measurements. For instance, the express service provided more stable data due to its direct route, while the transit service introduced variability due to intermediate stops. These insights underscore the need for a holistic approach to data collection and analysis in railway maintenance.

### 4.2 Recommendation

To address the challenges identified, the study proposed several actionable recommendations. First of all, upgrading measuring equipment and software would enhance data accuracy and reliability. Secondly, increasing the frequency of track inspections and fostering better communication between maintenance teams would help identify and resolve issues more promptly. The third one is standardizing the swaying measurement process by limiting the number of personnel involved could improve consistency. Moreover, implementing a speed management strategy, especially in zones where swaying is prevalent, could mitigate swaying severity. Last but not least, enhancing quality control in wheel profiling through standardized procedures and post-maintenance validation would ensure more predictable outcomes. These recommendations aim to improve passenger comfort, operational safety, and the overall resilience of the railway system.

### 5. Conclusion

This study intended to investigate the effect of wheel and track wear on train swaying, a significant issue determining ride comfort and operational safety in rail systems. The study successfully identified critical variables that determine swaying levels by combining historical data analysis, expert consultation, and real-time field measurements using the Xsens Motion Tracker. These variables include track imperfections, wheel flange wear, and train speed. Wheel reprofiling efforts (WP1 and WP2) had inconsistent outcomes, with WP1 indicating delayed improvement and WP2 resulting in increased swaying, especially on Track 2 where values rose up to 0.63 m/s<sup>2</sup>. These findings show that wheel maintenance is insufficient without coordinated efforts in track condition monitoring and speed regulation. Future researchers should focus on developing uniform measurement techniques, using high-resolution diagnostic technology, and promoting data-sharing frameworks between rolling stock and infrastructure agencies. This would result in a more comprehensive and accurate understanding of swaying dynamics, eventually leading to more resilient, comfortable, and safe railway systems.

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## Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

## Author Contribution

The authors confirm contribution to the paper as follows: A **Study of Impact of Wheel and Track Wear on Train Swaying**: Luqman Hakimi bin Taufiq, **Supervisors**: Dr. Nurul Farhanah binti Muarat and Ts, Amir bin Nordin. All authors reviewed the results and approved the final version of the manuscript.

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