



# FREIGHT WAGON FAILURES AS A BASIS FOR SAFETY-ORIENTED MAINTENANCE MANAGEMENT UNDER EUROPEAN RAILWAY REGULATIONS

Marija VUKŠIĆ POPOVIĆ<sup>1</sup> [0009-0001-2422-1276]

Aleksandar BLAGOJEVIĆ<sup>2</sup> [0009-0007-8100-1310]

Srdan STOJČIĆ<sup>3</sup>

Jevrem ROGIĆ<sup>4</sup>

Dušan VUJOVIĆ<sup>5</sup>

**Abstract** – The technical condition of freight wagons has a direct impact on railway safety and maintenance efficiency. This paper presents an analysis of failures recorded during technical inspections of freight wagons operated by Serbia Cargo and rented wagons over the period from September 2022 to January 2024. A database of recorded defects was analysed using descriptive statistical methods to identify the most failure-prone wagon subsystems and evaluate their significance for safety-oriented maintenance management. The results show that the brake system represents the most critical subsystem, accounting for 36% of failures in Serbia Cargo wagons and 56% in rented wagons. Brake block wear was identified as the dominant failure mode, while failures of pneumatic and mechanical brake components may directly affect braking performance and operational safety. A simplified Failure Mode Analysis (FMA) was performed to assess the risk associated with the most critical brake component failures. The findings indicate that systematic analysis of technical inspection data provides valuable support for risk-based maintenance planning in accordance with the Common Safety Methods (CSM) and the responsibilities of the Entity in Charge of Maintenance (ECM). The proposed maintenance and organizational measures contribute to improving railway safety and harmonizing maintenance practices with European railway regulations.

**Keywords** – freight wagons, brake system, maintenance management, railway safety, failure analysis, ECM, Common Safety Methods (CSM), risk assessment.

## 1. INTRODUCTION

The brake system is one of the most safety-critical subsystems of a freight wagon. Therefore, maintaining its operational reliability is essential for railway safety. Continuous monitoring of brake failures provides valuable information for improving maintenance strategies and reducing operational risks. This study analyses failures recorded during technical inspections of freight wagons operated by Serbia Cargo in order to identify the most failure-prone components and propose maintenance improvements.

Based on the failure records of freight wagons operated by "Serbia Cargo" from September 2022, to January 2024, at technical wagon inspection (TWI) points at Užice Traction and TWI Section, an analysis was conducted to identify the subsystems with the highest failure rates [1]. The causes of failures were determined, particularly for safety-critical assemblies such as brakes, and proposals for their mitigation were put forward. Technical non-conformity of vehicles (especially brakes) represents one of the primary sources of risk in the railway system.

<sup>1</sup> Academy of Technical and Art Applied Studies Belgrade, School of Railroad Transport, Belgrade, Serbia, marija.vuksic.popovic@vzs.edu.rs

<sup>2</sup> Academy of Technical and Art Applied Studies Belgrade, School of Railroad Transport, Belgrade, Serbia, aleksandar.blagojevic@vzs.edu.rs

<sup>3</sup> Academy of Technical and Art Applied Studies Belgrade, School of Railroad Transport, Belgrade, Serbia, srdjan.stojic@vzs.edu.rs

<sup>4</sup> Serbia Cargo, Belgrade, Serbia, jevrem.rogic@gmail.com

<sup>5</sup> Academy of Technical and Art Applied Studies Belgrade, School of Railroad Transport, Belgrade, Serbia, dusan.vujovic@vzs.edu.rs

The Common Safety Methods (CSM) objectives and Common Safety Indicators (CSI) are established in accordance with EU directives 2016/798 [2]. This paper focuses on one of the key aspects, the technical reliability of vehicles as a prerequisite for achieving safety targets. Maintenance performed by the Entity in Charge of Maintenance (ECM) shall comply with the Common Safety Methods (CSM) to ensure that maintenance activities remain risk-based, traceable and consistent with European railway safety requirements. While the ECM serves as the entity directly responsible for the technical conformity of railway vehicles, the CSM provides a unified regulatory framework and methods by which this conformity is demonstrated and controlled.

The ECM ensures that the rolling stock is continuously monitored, analyzed, and documented. In doing so, it directly fulfills the requirements of the regulation on common safety methods for monitoring (CSM Monitoring), which mandates performance control and risk management. Through failure analysis and the implementation of corrective measures, the ECM contributes to the continuous improvement of safety. This paper provides an assessment of the impact of identified defects on the safety level of the system, alongside proposed mitigation measures aligned with EU requirements in the field of safety management for CSM and vehicle maintenance for ECM.

## 2. FAILURE ANALYSIS

To assess the state of functionality and identify the most frequent failures on freight wagons, tracking and logging of freight wagon defects was conducted at TWI points at stations Vreoci, Požega, Prijepolje Teretna, and the border stations of Serbia and Montenegro – Bijelo Polje. The inspections results analysed in this paper were from September 2022 to January 2024 both on company (Serbia Cargo) and rented wagons.

A total of 66% of recorded failures occurred on Serbia Cargo wagons, whereas rented wagons accounted for the remaining 34%. Brake-related failures account for 36% of Serbia Cargo wagons, whereas rented wagons have brake failure 56% [1]. Wagon body failures have 23% on rented wagons whereas on company wagons account for 42% failures (Fig. 1). Other subsystems show low failure rates with the exception of bogies, which account for 9% failure on company wagons. From the perspective of safety-oriented maintenance management, the brake system represents the most safety-critical subsystem. Therefore, the analysis was further expanded to examine brake system defects by components for both company and rented wagons.

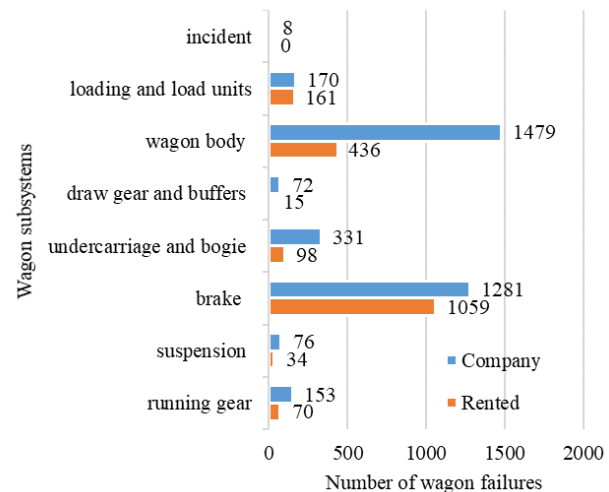


Fig. 1. Distribution of failures by wagon subsystems

The distribution of brake components failure on "Serbia Cargo" freight wagons shows highest rate of brake block failure (58%), while pneumatic component and mechanical component account for significantly less failures (Fig. 2). For rented wagons brake pneumatic components account for the largest share of brake failure (42%), followed by brake blocks (40%). Almost 91% of brake block failure are due to insert wear. This means that brake wear alone accounts for 36 % to 48% of the overall recorded failures. Brake failures predominated in Sgnss and Eanos company wagons and in Eanos and Sgns rented wagons.

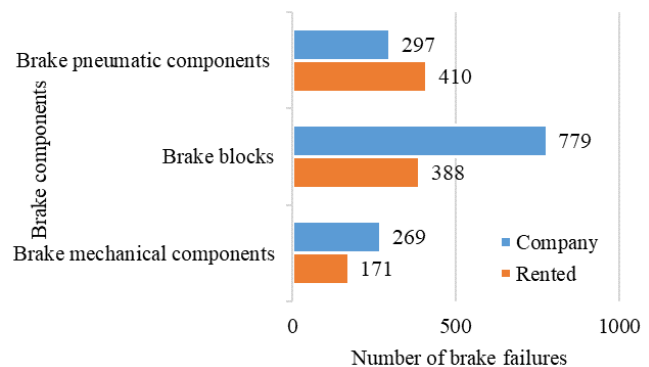


Fig. 2. Distribution of brake failures by component

The majority of failures on the brake pneumatic components can be rectified on-site—without decoupling the wagons—while they are still marshaled in the train formation. Alternatively, depending on the severity of the defect, the wagons can be sent to a workshop. Defects on the mechanical section of the brake system must generally be repaired in a workshop, with the exception of worn brake blocks, which can be replaced on-site.

## 3. SAFETY IMPLICATIONS AND MAINTENANCE MANAGEMENT

The results indicate that brake block wear represents the most significant maintenance issue.

Although primarily associated with increased maintenance costs, excessive wear may also reduce braking efficiency if replacement intervals are exceeded. Failures affecting pneumatic and mechanical brake components may reduce the effective braking mass of the train. Consequently, the required braking distance may not be achieved, increasing the risk of signal overruns or collisions. The results represent a good basis for CSM risk assessment whereas obtained data can be used as input for CSI. Also ECM should use results of TWI inspection to correct maintenance plans.

The rank of severity (S) and frequency (F) have values between 1 and 5, so the risk evolution in Risk Priority Number (RPN) range from 1 to 25. An overview of risk assessment using Failure Mode Analysis (FMA) for freight wagon failures is given in (Fig. 3). Severity (S) is in accordance with the defined classes of failure given in AVV, Annex 9 (1 – insignificant failures that correspond to low severity and 5 – critical failures that correspond to high severity). Frequency (F) was based on the obtained failure frequency data.

Tab.1. Risk analysis of freight wagon failures

| Component                                             | Failure root cause                                                                                | Failure             | Severity (S) | Frequency (F) | Risk Priority Number (RPN) |
|-------------------------------------------------------|---------------------------------------------------------------------------------------------------|---------------------|--------------|---------------|----------------------------|
| Brake mechanical components                           |                                                                                                   |                     |              |               |                            |
| Broken or hanging brake rigging components            | overload, corrosion, initial crack, material fatigue                                              | fracture or fallout | 4            | 2             | 8                          |
| Defective brake triangle support bracket              | overload, corrosion, initial crack, material fatigue                                              | fracture or fallout | 4            | 1             | 4                          |
| Brake distributor isolating cock                      | external damage, corrosion, initial crack, material fatigue                                       | damage              | 3            | 1             | 3                          |
| Brake force changeover device and brake mode selector | blocked valves, rust in the device, clogged nozzles                                               | unusable            | 3            | 1             | 3                          |
| Brake release pull wire broken or missing             | external damage, corrosion, initial crack, material fatigue                                       | damage              | 3            | 1             | 3                          |
| Hand parking brake                                    | external damage, corrosion, initial crack, material fatigue                                       | damage              | 4            | 1             | 4                          |
| Brake block                                           |                                                                                                   |                     |              |               |                            |
| Cast iron brake block                                 | missing, worn out, cracked                                                                        | damage              | 3            | 4             | 12                         |
| Composite brake block                                 | missing, worn out, cracked, material crushing                                                     | damage              | 3            | 1             | 3                          |
| Brake block overhanging the wheel tread               | displaced                                                                                         | damage              | 3            | 1             | 3                          |
| Brake pneumatic components                            |                                                                                                   |                     |              |               |                            |
| Main brake pipe                                       | external damage, corrosion, initial crack, material fatigue                                       | unusable            | 4            | 1             | 4                          |
| Brake hose coupling support bracket defective         | external damage, tire aging                                                                       | damage              | 3            | 1             | 3                          |
| Air brake inoperative but not isolated                | external damage, loosening of the joint                                                           | damage              | 3            | 2             | 6                          |
| Brake pipe end cock                                   | external damage, corrosion, initial crack, material fatigue does not seal, warped, missing handle | missing or unusable | 5            | 1             | 5                          |
| Derailment detector                                   | external damage, missing,                                                                         | damage              | 4            | 1             | 4                          |

The analysis of the risk of brake components failure showed that the RPN is the highest for component failure with the consequence of impact or collision due to a failure of brake. Brake failure of one wagon, lead to shortage of braking efficiency and can lead to signal overrun. Limited RPN value was set at 6 according to RNP rate in EN 50126 series standard set. The most critical component failures are

(Fig. 3):

- Broken or hanging brake rigging components - although it does not occur often, the seriousness of the consequences is great, so RPN = 8.
- Cast iron brake block - although it does not occur often, the lack or damage of one or more inserts, together with the high severity of the consequences, gives a high risk, so RPN = 12

- Air brake inoperative but not isolated, the frequency of occurrence is not high, but the severity of the consequences is moderate, so RPN = 6.

The high percentage of brake failures is strongly influenced by operating conditions on the Resnik–Bar railway line. Long descending gradients require intensive braking, resulting in accelerated wear of brake blocks and increased thermal loading of brake components. Wider application of regenerative braking could significantly reduce brake block consumption and improve maintenance efficiency.

Based on the analysis increased controls of certain types of wagons or components are proposed well as failure reporting and analysis system (feedback loop) so that the data from the TWI are used for the revision of maintenance plans (reduction of deadlines for critical components). This will increase safety and improve CSM monitoring. Also specific training for TWI inspectors and train drivers on the recognition of brake failure, which are often not visible during visual inspection, are proposed. The presented failure statistics enable maintenance decisions to be based on measured reliability data rather than fixed maintenance intervals.

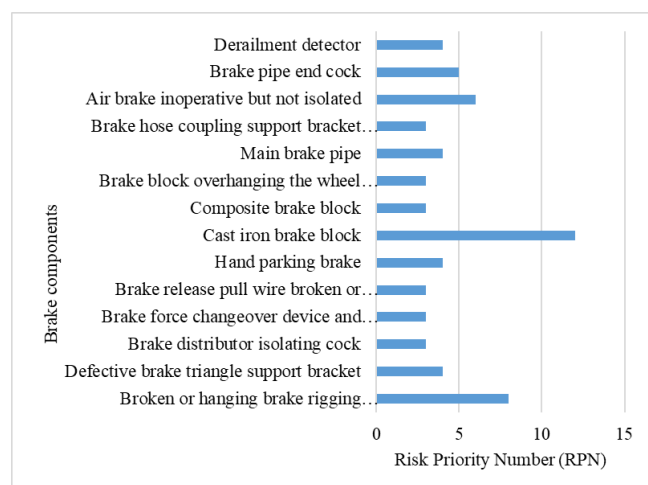


Fig. 3. Risk Priority Number (RPN) for the most critical brake failures

#### 4. CONCLUSION

The highest failure of "Serbia Cargo" freight wagons were detected on wagon body and the brake system. The largest failures (brake block wear)

represents not only an operating cost, but also a potential safety risk if it is not managed adequately (timely replacement, control on the track, etc.). Brake block wear represents the dominant degradation mechanism observed in the analysed fleet and should therefore be considered the primary maintenance indicator for freight wagons operating on mountain railways. Proposed measures like improvement of the feedback loop, targeted controls, application of composite brake blocks represent a step towards harmonizing the maintenance system with the requirements of the EU regulations on ECM and CSM, which directly contributes to raising the level of safety on Serbian railways. Future research should extend the proposed methodology to other railway corridors and evaluate the cost-effectiveness of advanced diagnostic systems and predictive maintenance techniques.

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