



## DELAY TRENDS IN RAIL FREIGHT TRANSPORT DUE TO TEMPORARY UNAVAILABILITY OF INFRASTRUCTURE

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### Abstract

Rail freight transport is a key component of Austria's supply chain and overall economic competitiveness. As a major transit country within the European rail network, Austria relies heavily on a resilient and reliable railway infrastructure. In this context, transport system stability refers to the ability of rail operations to absorb disturbances without causing persistent delays or disruptions. Temporary infrastructure and operational unavailability can therefore have substantial effects on the stability and punctuality of freight train operations. The impact of temporary unavailability on the arrival punctuality of freight trains on the Austrian rail network is analyzed. The analysis is based on comprehensive operational data from the year 2023. The dataset includes all freight train movements, planned infrastructure restrictions documented through operational and construction instructions (BETRA – Betriebs- und Bauanweisung, i.e. official railway operating and construction instructions), short-term operational interventions by rail traffic management, and category 1 disruptions (KAT1), which represent unplanned technical or operational incidents. Arrival delays are evaluated at the final destination of each freight train journey. The development of arrival delays is examined in relation to periods of temporary infrastructure and operational unavailability. The results indicate that unavailability is associated with a substantially higher occurrence of arrival delays in rail freight transport. In particular, delays that arise during periods affected by BETRA measures tend to persist over the remaining course of the journey and can only be compensated to a limited extent. Once established, delays often persist until the final destination of the freight train. The findings highlight the role of infrastructure-related constraints in reducing operational stability.

*Keywords: rail freight transport, temporary unavailability, arrival punctuality, delay propagation, infrastructure disruptions*

### 1 Introduction

Rail freight transport (RFT) constitutes a core element of Austria's national and international logistics system and plays a decisive role in ensuring economic competitiveness and security of supply [1]. Due to its geographical position at the intersection of major European transport axes, Austria functions as a key transit country for north–south and east–west freight flows. Several European rail freight corridors, including the Rhine–Danube and Baltic–Adriatic corridors, traverse Austrian territory, placing high demands on infrastructure capacity, reliability, and operational stability [2, 6]. A defining structural characteristic of the Austrian rail network is its predominantly mixed-traffic operation. Passenger and freight trains largely share the same infrastructure, as dedicated freight-only lines are mostly absent.

This shared use of infrastructure leads to strong capacity interdependencies between passenger and freight services, particularly on highly utilised main corridors. In such mixed-traffic systems, freight trains typically operate at lower maximum speeds, have longer braking distances, and are frequently assigned lower priority in dispatching decisions. As a result, freight services exhibit limited operational flexibility and increased vulnerability to capacity restrictions and disturbances [3, 4].

Rail freight transport is embedded in complex transport chains and encompasses heterogeneous production systems, including single wagonload traffic, block train operations, and combined transport. While these systems differ in their operational characteristics and flexibility, all freight services are affected by infrastructure availability and capacity management within the shared network [4, 5]. Punctuality therefore represents a critical performance indicator in rail freight transport, as delays directly affect logistics chains, terminal operations, and customer reliability [3]. Temporary infrastructure unavailability represents a major challenge for reliable freight train operations in mixed-traffic networks. Planned construction and maintenance activities, as well as unplanned operational disturbances, reduce available capacity and operational flexibility. In Austria, such restrictions are documented through BETRA (operational and construction instructions) and may include track closures, speed restrictions, or operational constraints affecting restrictions, signalling systems, or overhead lines [5]. The impacts of these measures are particularly severe on highly utilised corridors, where limited rerouting and overtaking options constrain operational responses.

Despite the high relevance of infrastructure availability in mixed-traffic rail networks, empirical analyses quantifying the network-wide impact of temporary infrastructure unavailability on rail freight transport remain limited. Existing studies frequently focus on passenger transport or on individual corridors rather than freight operations at the scale of an entire national network. Research on delay propagation and capacity constraints suggests that freight services are particularly susceptible to infrastructure-related disturbances due to lower priority and reduced recovery potential [7, 8]. This study addresses this gap by systematically analysing the relationship between temporary infrastructure unavailability and delay development in Austrian rail freight transport. The analysis is based on comprehensive operational data from 2023 and examines infrastructural and operational boundary conditions, with a particular focus on delay propagation and the relationship between entry delays and arrival punctuality.

## 2 Methodology

The methodological approach focuses on the temporal extent of infrastructure and operational unavailability because duration provides a more detailed measure of operational impact than event frequency alone. While the number of events describes how often disruptions occur, their duration more accurately reflects the potential consequences for rail operations. For this reason, the duration of unavailability is explicitly considered and classified into predefined time intervals. The delays of freight train arrivals were derived from comprehensive operational data for the year 2023. Due to the large data volume of more than 13 million records, data processing was carried out in an automated manner using Python-based workflows. For each freight train journey, the time difference between scheduled and actual running times was calculated. The first and last recorded events of each train journey were used to determine the arrival delay at the final destination. Based on these calculations, freight train journeys were classified according to their arrival status (early, punctual, or delayed), forming the basis for the subsequent analyses. To enable an integrated analysis of freight train movements and infrastructure-related events, all relevant data sources were harmonised regarding their spatial and temporal references.

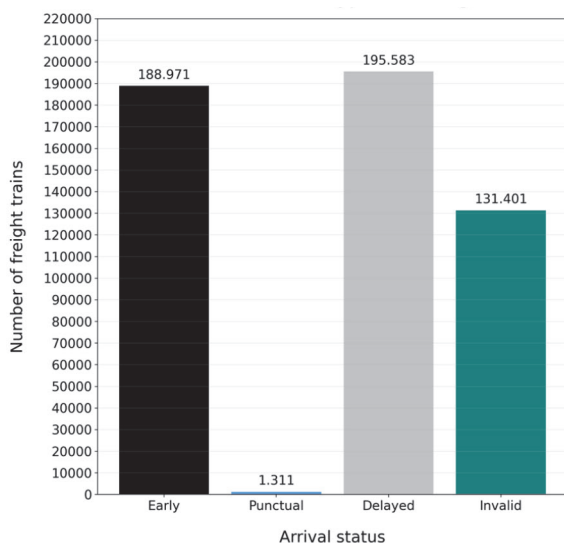
Station identifiers were standardised using a uniform reference format to ensure consistent spatial matching across datasets. Date and time information was combined into unified timestamp variables to facilitate temporal alignment. In addition, the duration of events relating to BETRA measures, operational interventions by traffic management, and category 1 disruptions (KAT1) was calculated using recorded start and end times.

A spatio-temporal matching procedure was then applied to identify overlaps between freight train movements and periods of infrastructure or operational unavailability. This matching was based on spatial coincidence at the station level and temporal overlap between train movements and event intervals. Both the scheduled and actual running times of freight trains were considered in order to capture overlaps under both planned and realised operating conditions. To ensure computational feasibility, the matching process was conducted in batches, while preserving the integrity of individual train journeys. Following the matching process, the resulting datasets were consolidated and subjected to quality checks to remove any incomplete or implausible entries. Analyses were performed both at the level of individual freight train journeys and at an aggregated train level, allowing the assessment of affected journeys as well as affected trains. Finally, the durations of infrastructure and operational unavailability were classified into predefined time categories ranging from short-term disruptions to long-term unavailability. This classification provides the basis for the comparative analysis of how delays develop under different types and durations of unavailability. Duration and delay propagation analyses are restricted to BETRA measures, since short-term operational interventions do not provide a comparable temporal scope. Although category 1 disruptions (KAT1) are included in the dataset, they are not analysed separately in the results, as their point-like occurrence and very short duration do not allow for a meaningful assessment of system-wide effects or delay propagation.

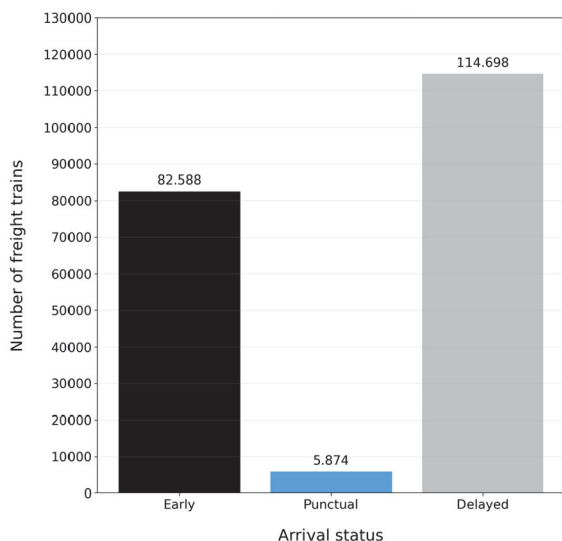
### 3 Empirical results

The analysis reveals a clear relationship between freight train delays and periods of temporary infrastructure and operational unavailability on the Austrian rail network. Based on freight train movements linked to BETRA measures using actual running times, the following results quantify delay patterns, spatial concentration effects, and delay propagation mechanisms. The distribution of arrival statuses of freight trains in the Austrian rail network in 2023 reveals a clear dominance of delayed arrivals. The results show that delayed arrivals are more frequent than punctual arrivals, highlighting the vulnerability of rail freight transport to capacity constraints and operational disturbances. While a significant proportion of freight trains arrive earlier than scheduled, reflecting timetable buffers and operational variability, these buffers are insufficient to offset delays once they occur.

Figure 1 illustrates this distribution and provides the baseline for the subsequent analyses focusing on infrastructure-related delay mechanisms. The effects of temporary infrastructure and operational unavailability on freight train punctuality are illustrated in figures 2 and 3. Figure 2 shows the arrival status of freight train movements affected by planned infrastructure measures (BETRA), while figure 3 presents the corresponding results for short-term operational interventions by traffic management. During BETRA periods, delayed arrivals clearly dominate the distribution, indicating a strong impact of planned construction and maintenance activities on freight train punctuality.

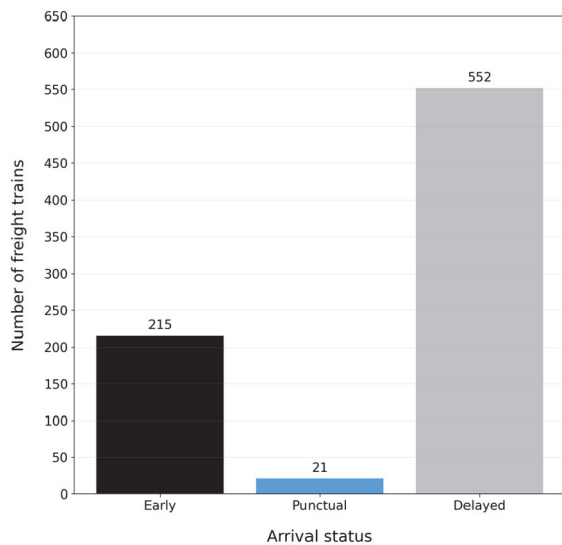


**Figure 1** Distribution of arrival types for freight trains

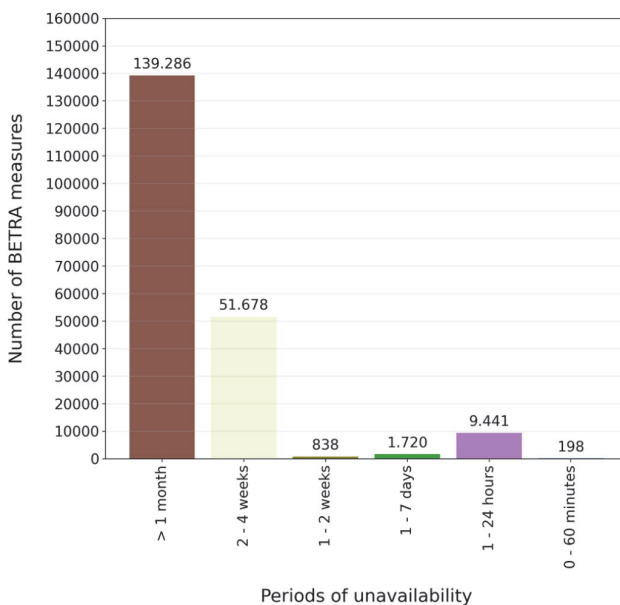


**Figure 2** Arrival status of freight trains during BETRA measures

Figure 4 illustrates the duration of planned infrastructure unavailability caused by BETRA measures. The results show that a substantial share of BETRA-related restrictions persists over extended periods, often lasting several weeks or months. Such long-lasting capacity reductions severely limit operational flexibility and contribute to persistent delay accumulation across the network. In contrast, short-term infrastructure restrictions occur less frequently and exhibit a comparatively lower impact on overall delay development.



**Figure 3** Arrival status of freight train journeys in the event of operational measures



**Figure 4** Duration of unavailability due to BETRA measures

The relationship between entry delays and arrival delays is examined in figure 5, which compares the statistical distributions of delays at the beginning of a train’s journey and at its destination. In this context, the break-in delay refers to the delay recorded at the first operational event of each freight train journey. The results show a clear increase in median arrival delay with higher break-in delay classes. This indicates that initial delays tend to persist and frequently grow over the course of the journey. The widening distribution and pronounced upper tails for higher delay classes further confirm a strong delay propagation effect under capacity-constrained conditions.

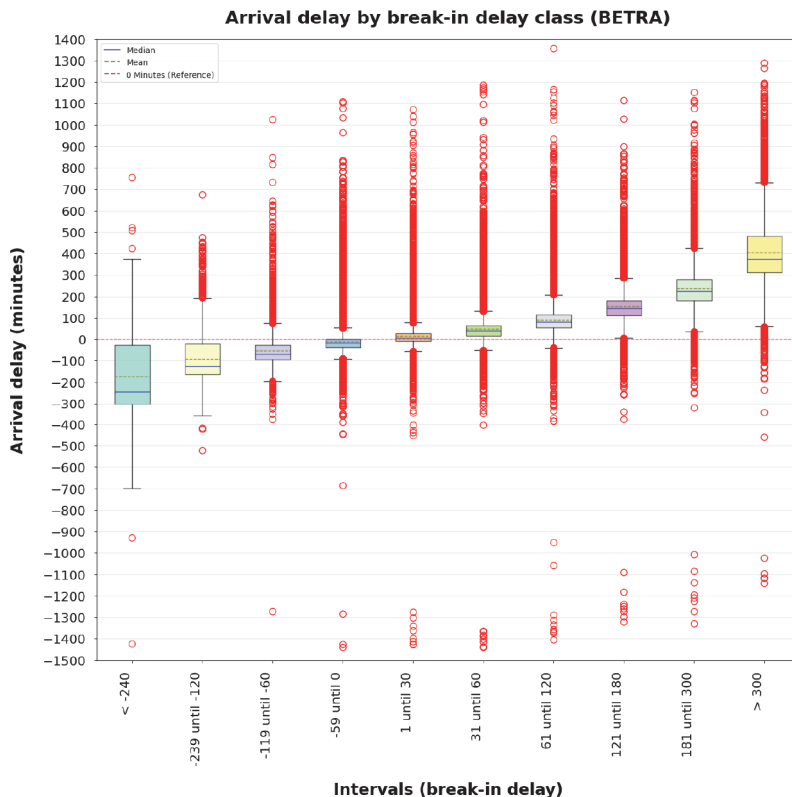


Figure 5 Statistical analysis of arrival delay by break-in delay class (BETRA measures)

Overall, the results show that temporary infrastructure-related constraints increase both delay occurrence and delay persistence. These findings are discussed in the following section.

## 4 Conclusion

The results confirm that temporary infrastructure and operational unavailability are key factors in delay development in Austrian rail freight transport. Although essential for maintaining and improving network quality, planned infrastructure measures impose substantial operational impacts during their implementation. In particular, long-lasting BETRA measures reduce available capacity over extended periods and lead to persistent delay accumulation. The analysis further shows that the recoverability of delays in rail freight transport is limited. Structural characteristics such as lower operational priority compared to passenger services, restricted overtaking possibilities, and tight capacity margins contribute to this effect. Once delays occur, they tend to spread across the network. This effect is especially pronounced on heavily used main corridors, where even minor capacity restrictions can have widespread consequences. Short-term operational measures by traffic management affect fewer freight train movements in absolute terms. However, the proportion of delayed trains during such events is comparatively high. This indicates that short-term disturbances often occur under already constrained operational conditions. As a result, there is little room for recovery. Overall, the findings highlight that improving the robustness of rail freight operations requires a proactive and integrated approach.

Key measures include the construction of realistic timetables with adequate buffer times, the coordination of infrastructure and construction planning, and the enhancement of operational flexibility on critical network sections. Addressing these aspects is particularly important on heavily used main corridors, where targeted interventions can significantly improve system performance.

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