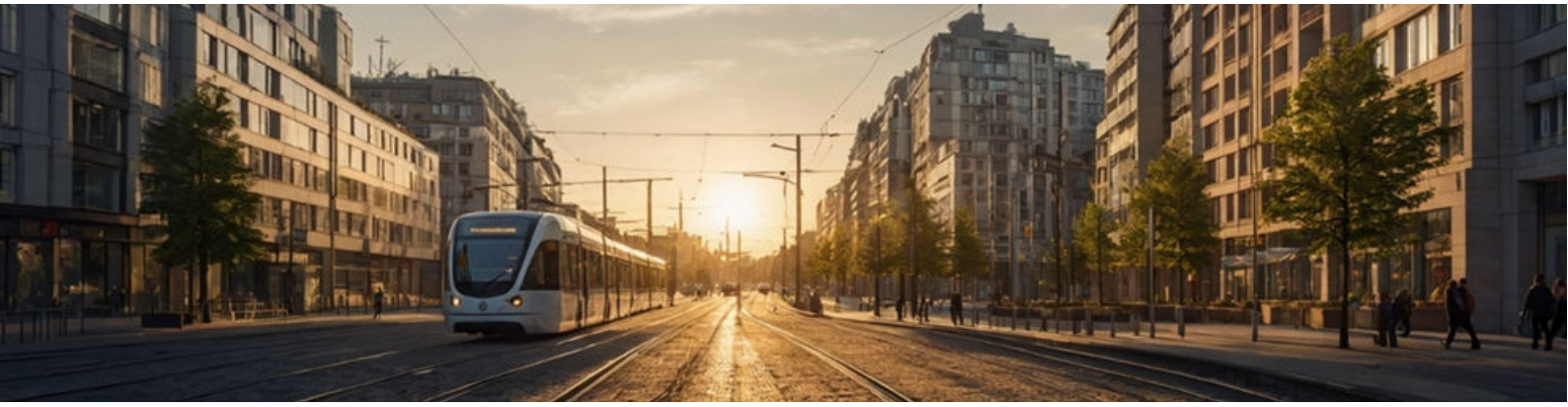


CURVE NOISE IN TRAM SYSTEMS - A HIDDEN COST OF URBAN MOBILITY



Urban tram systems are the cornerstone of sustainable public transport. Their integration into dense city environments offers a low-emission, space-efficient alternative for mobility. However, one persistent issue undermines both operational efficiency and public perception: curve noise. This high-frequency squeal, most noticeable in tight-radius curves, is not merely an acoustic nuisance. It is a mechanical signal of stress, inefficiency, and degradation at the wheel-rail interface. Curve noise has two distinct forms: squeal, which occurs primarily in tight-radius curves due to stick-slip oscillations, and flange contact noise, which can also occur on straight sections due to wheel-rail contact at the flange.



UNDERSTANDING CURVE NOISE ; THE MECHANICS OF WHEEL-RAIL INTERACTION

Curve noise, or wheel squeal, originates from the dynamic interaction between the tram's wheelset and the rail during lateral movement. As a tram enters a curve, the wheelset experiences an angle of attack relative to the rail. This misalignment generates lateral forces and stick-slip oscillations at the contact patch. These forces are particularly pronounced in tight curves, where the wheelset cannot align naturally with the track geometry. The result is a high-pitched squeal, often exceeding 90 dB(A).

Such noise levels are not just a technical concern. They have a direct impact on the surrounding. In urban environments, this squeal can cause significant noise nuisance for pedestrians and cyclists just a few meters from the track, and even for residents inside nearby homes, especially in densely built areas. The acoustic energy can penetrate façades and contribute to daily noise annoyance, particularly during early morning or late evening tram operations.

CONDITIONS THAT AMPLIFY SQUEAL

Several factors exacerbate curve noise:

- Small curve radii
- Dry or poorly lubricated rails
- Worn or mismatched wheel and rail profiles
- Inadequate cant
- High vehicle speeds in curves

These conditions increase the likelihood of unstable lateral vibrations, which manifest as audible squeal.

CONSEQUENCES OF CURVE NOISE

DEGRADATION INFRASTRUCTURE AND WHEELS

The mechanical energy that produces curve noise also accelerates wear on the railheads and wheels. For Infrastructure, over time, this leads to surface defects such as corrugation, spalling and/or head checks. These defects degrade ride quality, increase rolling resistance, and require frequent grinding and rail replacement.

In extreme cases, repeated lateral loading can deform track geometry, leading to gauge widening, cant deficiency, and even track buckling. These issues increase maintenance costs and pose safety risks and reduce network availability.



FLEET WEAR AND MAINTENANCE

The fleet is equally affected. Excessive lateral forces contribute to accelerated wheel flange wear, necessitating more frequent re-profiling. Bogie and suspension systems endure increased dynamic loads, which lead to reduced component lifespan or even fatigue failures. These stresses reduce fleet availability and increase maintenance costs, threatening the economic efficiency of tram operations.



ENVIRONMENTAL AND SOCIAL IMPACT

In residential areas, curve squeal is a major source of urban noise pollution. Studies have linked chronic exposure to rail noise with sleep disturbances, cardiovascular stress, and reduced quality of life for residents. Public perception of trams as quiet and sustainable is compromised, and regulatory bodies are responding with stricter noise limits.

In the European context, noise from rail transport is now recognized as one of the seven major environmental hazards, prompting cities to adopt noise action plans and mitigation efforts.

CURVE NOISE AS A DIAGNOSTIC SIGNAL

Curve noise should not be treated as a mere byproduct of tram operation. It is a real-time, measurable indicator of system health. When properly monitored and analyzed, it provides valuable insight into the condition of both infrastructure and rolling stock.

Acoustic and vibrational monitoring enables the detection of:

- High-friction zones, which may indicate lubrication failure or rail contamination
- Wheel profile degradation, which affects contact geometry and stability
- Track geometry issues, such as cant deficiency or alignment errors
- Vehicle-specific anomalies, including bogey misalignment or suspension faults

By interpreting curve noise as a diagnostic signal, operators can shift from reactive to predictive maintenance. This approach reduces unplanned downtime, extends asset life, and improves overall system resilience.

SMART ASSET MANAGEMENT WITH SENSORNET SAM

The Sensornet SAM platform provides a modular and data-driven approach to managing tram infrastructure and fleet health. It converts acoustic and vibration signals into actionable insights for predictive maintenance and for reducing operational and environmental impact. The modules are focused on specific application areas: trackside, onboard, and environmental monitoring. This enables operators to address curve noise and its consequences in a smart and targeted way.

SAM CURVE

SAM Curve helps operators address curve squeal by detecting and localizing noise events using onboard sensors. It identifies the exact location, intensity, and frequency of squeal, allowing onboard lubrication systems to apply grease precisely—only where and when needed, and in the correct dosage.

The system is modular and scalable. It can start with a basic microphone setup that detects squeal in real time and trigger lubrication immediately. More advanced configurations include GPS, vibration sensors, and algorithmic learning that builds a database of squeal-prone locations. This allows the system to anticipate noise events and act proactively, even sharing data between vehicles to reduce the need for full instrumentation across the fleet.

By reducing friction and wear, SAM Curve extends the lifespan of both wheels and rails. It also cuts down on lubricant use and urban pollution, while improving ride comfort and reducing complaints. A case for The Hague, the system granted the department Infrastructure a potential annual cost saving of over €400,000, simply by extending curve life and optimizing lubrication. A conservative calculation, because the Fleet departement was not involved in this case.

KEY FEATURES SAM CURVE

- Real-time detection of curve squeal
- Automatic control of onboard lubrication systems.
- Modular setup: microphone-only to full sensor suite with GPS, communication and vibration.
- AI-based learning and location database.
- Data sharing between vehicles.

BENEFITS SAM CURVE

- Reduced wear on wheels and rails.
- Lower lubricant consumption and pollution.
- Fewer noise complaints.
- Extended curve lifespan (from 8 to potentially 30 years).
- Extended wheels lifespan
- Significant annual cost savings

SAM INFRA

SAM Infra transforms regular service vehicles into mobile inspection units. Sensors mounted on the vehicle continuously measure sound, vibration, acceleration, and displacement, along with GPS location, speed, and environmental conditions. This data is processed into high-resolution insights, revealing hotspots, early-stage damage, and trends like corrugation or squats.

The system supports infrastructure managers in planning maintenance based on actual condition rather than fixed schedules. It generates automatic alerts, exports data to GIS or rail asset systems, and allows filtering by time, vehicle, or severity. Because it uses representative vehicles under normal conditions, the insights are both accurate and actionable.

SAM Infra has proven its value in cities like Amsterdam, Utrecht, Den Haag, Fribourg, Rotterdam and Zagreb, supporting grinding plans, identifying weld failures, and helping prioritize interventions.

KEY FEATURES SAM INFRA

- Continuous onboard monitoring using sound, vibration, and GPS.
- High-resolution FLAC audio and vibration data.
- Real-time dashboards and automatic alerts.
- Integration with GIS and asset management systems.
- Filtering by time, vehicle, attribute, and severity.

BENEFITS SAM INFRA

- Early detection of track defects (e.g. squats, shelling, weld fractures).
- More effective manual inspections.
- Condition-based, data-driven maintenance planning.
- Representative data from real-world operations.
- Easier achievement of performance and safety KPIs.

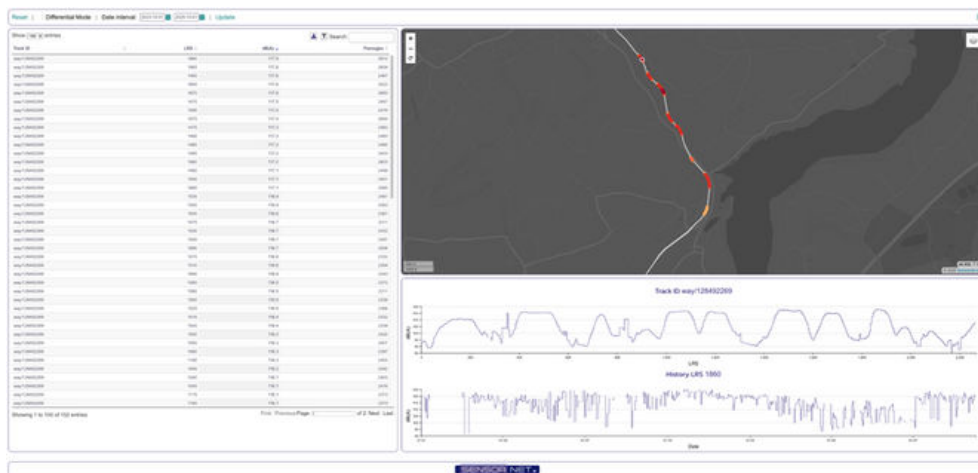


Figure 1: Example SAM, module Curvenoise for one of our customers (anonymised)

SAM FLEET

SAM Fleet monitors the condition of passing vehicles using wayside sensors. It detects wheel defects such as flat spots and out-of-roundness, and correlates these with noise and vibration emissions. These issues often point to deeper mechanical problems like gearbox wear or suspension faults.

The system provides real-time alerts and detailed dashboards for both technicians and managers. It can generate recordings of each pass-by for acoustic and vibrational analysis, enabling fast and targeted maintenance. At GVB Amsterdam, SAM Fleet contributed to a 42% reduction in noise complaints by enabling better wheel profiling and faster response to emerging defects.

KEY FEATURES SAM FLEET

- Wayside sensors for vehicle condition monitoring.
- Detection of wheel defects and abnormal emissions.
- Real-time alerts and acoustic recordings.
- Dashboards for technicians and management.
- Integration with vehicle ID and maintenance systems.

BENEFITS SAM FLEET

- Faster response to emerging defects.
- Reduced noise complaints (42% reduction at GVB).
- Improved fleet availability.
- Lower maintenance costs.
- Data-driven wheel profiling and depot planning.



Figure 2: Reporting tools for SAM

CONCLUSION

Curve noise is not an incidental byproduct of tram operation. It is a measurable, interpretable signal of systemic inefficiency. By leveraging advanced monitoring and analytics, operators can transform this challenge into a strategic advantage. Sensornet's SAM platform, through its Curve, Infra, and Fleet modules, enables a shift from reactive to proactive asset management. The result is quieter, more efficient, and more resilient urban mobility.

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