CHALMERS

CHALMERS

Research report 2024:04

Towards improved regulations and procedures for damaged wheels – Assessment of wheel impact load detectors

JENS NIELSEN
LARS FEHRLUND
MICHELE MAGLIO
PÄR SÖDERSTRÖM
ANDERS EKBERG
ELENA KABO
TORE VERNERSSON

Department of Mechanics and Maritime Sciences
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2024

Research report 2024:04

Towards improved regulations and procedures for damaged wheels – Assessment of wheel impact load detectors

by

JENS NIELSEN
LARS FEHRLUND
MICHELE MAGLIO
PÄR SÖDERSTRÖM
ANDERS EKBERG
ELENA KABO
TORE VERNERSSON

Department of Mechanics and Maritime Sciences
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden, 2024

Towards improved regulations and procedures for damaged wheels – Assessment of wheel impact load detectors

JENS NIELSEN, LARS FEHRLUND, MICHELE MAGLIO,
PÄR SÖDERSTRÖM, ANDERS EKBERG, ELENA KABO,
TORE VERNERSSON

Research report 2024:04

Department of Mechanics and Maritime Sciences
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone +46 (0)31 772 1000

Executive summary

To increase passenger and freight traffic, railway transportation needs to be safe, reliable, environmentally friendly, cost-efficient, and on time. To this end, railway wheels that are not perfectly round because of some type of mechanical damage on part of the running surface (wheel tread) should be avoided as they may lead to severe loading and damage of the track. Resulting infrastructure failures, such as rail breaks, could cause severe traffic delays, derailment, and in the worst case, fatalities.

This is the reason why Trafikverket uses wayside wheel impact load detectors (WILD) in their network to measure the dynamic load generated by each passing wheel. Besides a limit on maximum allowed peak load, Trafikverket imposes regulations on the maximum allowed circumferential length of a wheel tread damage. The train must be stopped for visual inspection if the measured peak load exceeds the alarm limit 350 kN. If the wheel tread damage exceeds 60 mm in length, the vehicle with the damaged wheel must be taken out from the train independent of train speed and axle load. The stopped train (or wagon) might then block one track that should have been used for passing traffic. The resulting delay and required repair of this train leads to primary costs for the infrastructure owner (Trafikverket) and rolling stock operators (such as Green Cargo and SJ). Secondary costs in these events are caused by subsequent trains being delayed, inducing costs from reimbursing affected passengers/freight customers etc. This is a considerable issue in the Swedish railways, where a substantial part of the network is only single track.

Thus, regulations for removal of out-of-round wheels have a substantial influence on punctuality and costs. The implementation of WILDs to measure dynamic loads offers the opportunity to define a criterion for removal of wheels based solely on the measured load, thereby also removing the need for manual inspection and increasing employee safety. Overall, it is vital that the detectors have a robust and transparent calibration procedure to ensure accurate measurements of dynamic wheel loads, and that they are subjected to regular maintenance and monitoring of track geometry in the detector area.

The present study was carried out in the project *Improved regulations and procedures for damaged wheels*, which was funded by the Swedish innovation agency VINNOVA and performed 2023-07-01 – 2026-06-30 by representatives from Trafikverket, Chalmers University, Green Cargo and SJ. Parts of the study have been funded within the Horizon-ER-JU-2022-FA5-01 project TRANS4M-R under grant agreement no 101102009. The current report is the final deliverable from work package 1 in the VINNOVA project, and it has the following contents:

- The background to the VINNOVA project is presented in Section 1 of this report.
- In Section 2, the alarm limit and current regulations are summarised.
- The two types of WILD, Schenck and voestalpine zentrac, currently used in the Swedish network are described in Section 3. Trafikverket's regulations on their placement and calibration are summarised.
- A case study investigating measured data from six Schenck detectors along the route of Stålpendeln is presented in Section 4. In total, 823 detector passings by 149 different wheelsets (with at least one of the wheels on the axle being

defective) were included in the analysis. It is shown that no evident correlation between wheel flat length, train speed and peak load could be found. In parallel, for one investigated 75 mm long wheel flat, all measured peak loads and mean loads for two journeys in loaded conditions and three journeys in tare conditions have been studied. A large variation in measured loads between the different detectors is observed, indicating that besides the variation in speed and other influencing variables, the condition of the detectors might have affected the measured loads. The accuracy of the measured dynamic loads is unknown. Field measurements indicate that irregularities in track geometry and track stiffness might have contributed to the scatter in measured peak loads demonstrating the importance of regular monitoring of the conditions at the detectors.

- The consequences of out-of-round wheels in terms of rail damage and costs for Trafikverket are discussed in Section 5. Trafikverket stores information on the causes and consequences of each reported rail damage. In 2023, no rail breaks due to wheel flats or damaged wheels were reported. Inspections of vehicles or tracks (such as those occurring after alarm/warning levels) caused 1000 hours of delay in 2023, while they caused around 300 hours of delay in 2013.
- Mean loads and dynamic loads measured for two different bogie types used by Green Cargo are compared in Section 6. It is concluded that all studied detectors seem to measure mean loads accurately. However, there seems to be a seasonal variation in dynamic loads measured by the zentrac detectors, particularly for the unloaded vehicles and independent of braking system and bogie type. The reason for this is unknown and needs to be solved to minimise the risk of false alarms and unnecessary costs.
- The action plan used by SJ in case of a detector alarm is described in Section 7. Generally, very few SJ trains are stopped due to their active condition-based maintenance strategy. To specifically monitor wheel degradation and trends, Power BI-reports are generated. Quarterly, Trafikverket and the Railway Undertakers meet in a forum named ‘Industry common management detectors’ (Branschgemensam förvaltning Detektorer). To obtain a common understanding of the situation and aiming to focus on the incidences that lead to the highest negative impact in terms of delay minutes, a Power BI tool named ‘Common situation picture’ (Gemensam lägesbild) has been developed.

Contents

Preface

The work presented in this report is performed as a Parallel Special Project (SP37) within the Centre of Excellence CHARMEC (www.charmec.chalmers.se). The aims of the project are improved regulations and procedures to avoid traffic disruptions caused by infrastructure failures and unnecessary stopping of trains. It should also promote an increased collaboration and understanding between the infrastructure owner and the rolling stock operators. The project duration is 2023-07-01 – 2026-06-30.

Financial support was provided by VINNOVA (Sweden's innovation agency), contract no 2023-01218. This report summarises the work in the first work package (WP1) of the project.

Göteborg in November 2024

Jens Nielsen	Chalmers University of Technology
Lars Fehrlund	Green Cargo AB
Michele Maglio	Trafikverket
Pär Söderström	SJ AB
Anders Ekberg	Chalmers University of Technology
Elena Kabo	Chalmers University of Technology
Tore Vernersson	Chalmers University of Technology

1 Background

To increase passenger and freight traffic, railway transportation needs to be safe, reliable, environmentally friendly, (cost-)efficient, and on time. To this end, it is vital to control track deterioration (that relates to the majority of railway maintenance costs) and to carry out maintenance in an efficient manner that minimises traffic disruptions, costs, energy and material consumption. There are two aspects to this: (1) Vehicles that impose loads that may cause track failures should be restricted, and (2) the vehicle and track maintenance should consider operational loading to optimise inspections and maintenance.

Regarding the dynamic traffic loads on the track, wheels that are not perfectly round because of some type of mechanical damage on parts of the running surface (wheel tread) should be avoided as they lead to severe loading and damage of the track, impact noise and ground-borne vibration. Resulting infrastructure failures, such as rail breaks, can cause severe traffic delays, derailment, and in the worst case, fatalities. This is the reason why the infrastructure owner Trafikverket uses *wheel impact load detectors* (WILD) in their network to measure the dynamic load level from each passing wheel. Besides maximum allowed peak loads, Trafikverket also imposes regulations on the maximum allowed circumferential length of a wheel tread damage. WILD data provide operators with information on the status of their wheel fleet. The load levels can be used to schedule preventive maintenance actions of trains before wheel out-of-roundness grows to unacceptable levels. It can also be employed by infrastructure managers to plan rail inspections and maintenance before a rail crack grows to a size that requires rail replacement or poses a risk of causing a rail break.

The train must be stopped for inspection at the closest passing siding if the measured load exceeds the *alarm limit*. Based on a subsequent visual inspection, if the wheel tread damage exceeds 60 mm in length, the vehicle with the damaged wheel must be taken out from the train independent of train speed and axle load. The stopped train (or wagon) will then block one of the tracks in the passing siding. The resulting delay and required repair of this train leads to primary costs for the infrastructure owner (Trafikverket) and rolling stock operators, such as Green Cargo (freight traffic) and SJ (passenger traffic). Secondary costs in these events are caused by subsequent trains being delayed, inducing costs from reimbursing affected freight/passenger customers etc. This is a considerable issue in the Swedish railways, where a substantial part of the network is only single track. Altogether, this will have long-term negative impacts on the railway traffic in terms of reduced trust and confidence.

Thus, the regulations for removal of out-of-round wheels have a substantial influence on punctuality, costs and employee safety due to the manual wheel inspection in track. However, the implementation of calibrated WILDs with verified accuracy to measure dynamic loads offers the opportunity to define a criterion for removal of wheels based solely on the measured load, thereby removing the need for manual inspection. Imposed load limits then need to strike a fine balance between preventing failures and minimising the number of stopped trains. This is complicated by the fact that for a given wheel tread damage, the detected impact load level depends on the lateral position of the wheel–rail contact relative to the position of the tread damage, as well as on the impact position along the detector. In addition, the measured impact load depends on train speed and the dynamics of the coupled vehicle–track system. Altogether, this means that a given wheel tread irregularity in similar operating conditions is likely to generate different impact loads in two adjacent detectors, or even in the same detector on two different occasions. It has also been observed that the scatter in measured impact loads increases with increasing train speed.

2 Alarm limits and current regulations

To mitigate wheel–rail impact loading due to out-of-round wheels, the main priority should be to control and monitor the development of discrete wheel tread irregularities by vehicle and brake design, and by regular maintenance. Wheel damage can be detected by acoustic or visual inspections, and by measurements of vertical wheel–rail contact force in wheel impact load detectors (WILDs). In this way, condition monitoring of measured force levels provides operators with information on the status of their wheel fleet. In the case of evolving rolling contact fatigue (RCF) damage leading to moderate increases of peak loads with time, these force levels could be used to schedule preventive maintenance before the wheel out-of-roundness grows to unacceptable levels, while wheels with flats can be taken out of service for immediate corrective maintenance. Various types of sensors have been deployed in commercial wayside WILD systems to measure wheel–rail contact force. This includes strain gauge load circuits and fibre optic sensing technology for measurements of rail bending, and load cells for measurement of rail seat loads [1].

Based on post-processing of the measured signals, the detectors provide information about the mean load and peak load generated by each passing wheel. The dynamic load contribution and the ratio are also evaluated. The dynamic load is the difference between the peak load and the mean load, while the ratio is the peak load divided by the mean load. The peak load is useful for heavy haul operations with high axle loads to control that the wheels do not induce loads that could damage the track, while the ratio is mainly applied for unloaded wagons to detect wheel damage that could become harmful when the wagon has been loaded.

To prevent unacceptable deterioration levels and safety-related failures, alarm limits are prescribed. The UIC recommended alarm limit for peak load mandates an immediate stop of the train if the peak wheel–rail contact force exceeds 350 kN, with an alert level at 300 kN [2]. The regulations [3] applied by Trafikverket can be distinguished into ‘high’ and ‘warning’ alarm levels:

- For a passenger coach or a freight wagon, the ‘high’ alarm level is 350 kN. If this level is exceeded, the train may continue at reduced speed to the nearest passing siding where the vehicle with the wheel tread damage must be decoupled from the train [4].
- For locomotives, the ‘high’ alarm level is 425 kN.
- If a locomotive wheel generates a peak load exceeding 350 kN and the ambient air temperature is below -10 C°, train speeds in the interval 15 – 45 km/h should be avoided [3].
- ‘Warning’ levels are set at 280 kN (peak load), 180 kN (dynamic load) and 4.8 (ratio) independent of vehicle type.
- If the measured peak load, dynamic load or ratio exceeds a ‘warning’ level (but not the peak load 350 kN), the train may continue without regulations to its destination. From there it is not allowed to continue operating until the wheel has been rectified and approved by certified staff. This regulation holds unless it is found that the length of the wheel flat (tread damage) exceeds 60 mm.

3 Wheel impact load detectors

3.1 Wheel impact load detectors in Sweden

There are currently two types of wheel impact load detectors (WILDs) used in the Swedish railway network. In June 2024, this included 26 detectors named Wheelscan produced by Schenck, and 4 detectors named zentrak[1] Modular Diagnostic System (MDS) produced by voestalpine. The WILDs are placed throughout the network, from Vassijaure in the north to Dammstorp in the south. In a few cases, two detectors are placed in the same location on the northbound and southbound tracks of a double-track line (e.g. at Mellansjö, Kumla and Dammstorp). Most WILDs are located near a hot axlebox detector and a hot wheel detector.

The Wheelscan detectors, cf. Figure 2.1(a), consist of eight weighing sleepers, electrical equipment and a workstation for data processing [5]. Each weighing sleeper is equipped with two weighbeams (one below each rail). These beams are used to measure the vertical wheel loads (sum of static and dynamic loads) using strain gauges. There are two generations of Wheelscan detectors (Wheelscan1 and Wheelscan2). The first generation is characterised by deeper sleepers, which led to difficulties in performing track maintenance activities such as tamping. This resulted in undesired track settlements and to the adoption of detectors of the second generation Wheelscan2.

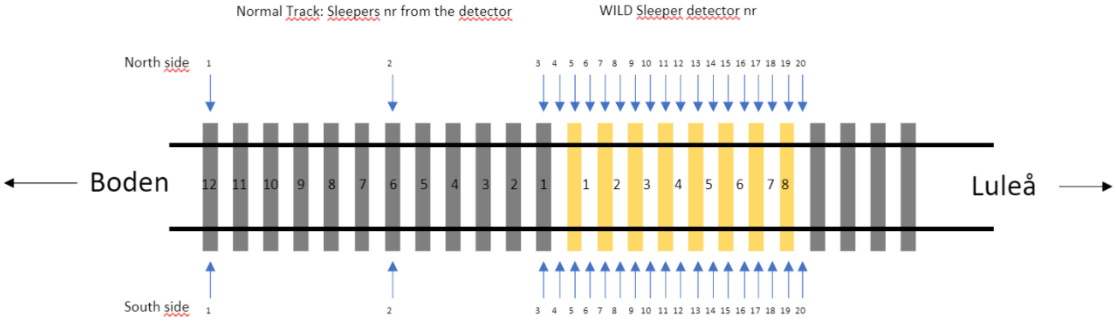
Measurements of rail accelerance (acceleration over force) have been carried out in the Wheelscan1 detector at Sunderbyn [6]. The rail was excited by an impact hammer at different positions within the detector as well as adjacent to the detector, while the acceleration of the rail head at the impact position was measured by an accelerometer, see Figures 2.1(b,c). The measurements were performed in September 2021 (ambient temperatures in the range 5 – 12 °C) with the most recent tamping of the detector carried out in May 2021. As indicated in Figure 2.1(d), the different superstructure design used in the detector compared to plain track has a significant influence on the rail accelerance. This could have an influence on the measured load magnitudes.

The zentrak detectors, cf. Figure 2.2, are based on sixteen fibre optic load sensors (eight per rail) designed to measure the relative rail rotation at the bottom of the rail foot as a result of rail bending during the passage of a train wheel [7]. The rail sensor is calibrated when installed or moved. The advantage with optical sensors is that measurements are not influenced by external electromagnetic disturbances, and that the sensor itself does not emit electrical disturbances and therefore has no influence on other devices mounted nearby [7]. The sensors are connected to a site detector cabinet by means of fibre optic cables. As the optical sensors are clamped under the rail foot, zentrak detectors cannot be distinguished from the rest of the line as easily as the Wheelscan detectors, see Figure 2.2.

---

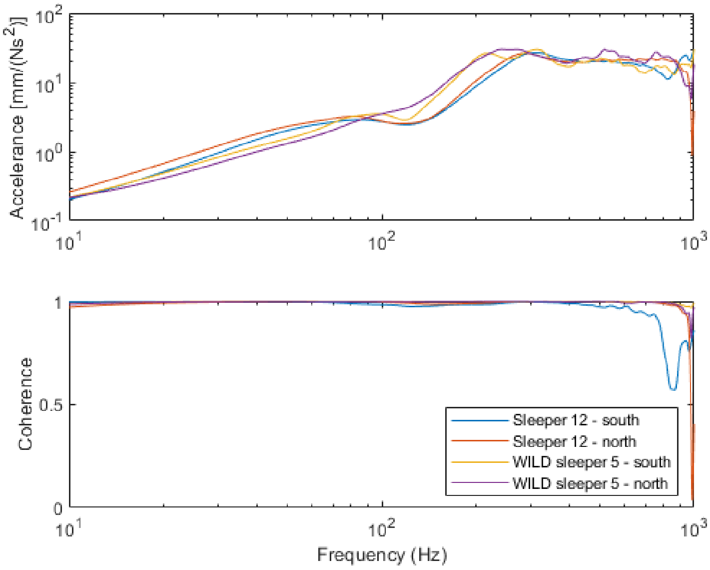
[1] Note that zentrak MDS by voestalpine Signaling was previously referred to as PHOENIX MDS.

(a)


Normal Track: Sleepers nr from the detector
WILD Sleeper detector nr
North side
South side
1
2
3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Boden
Luleå
12 11 10 9 8 7 6 5 4 3 2 1
1 2 3 4 5 6 7 8

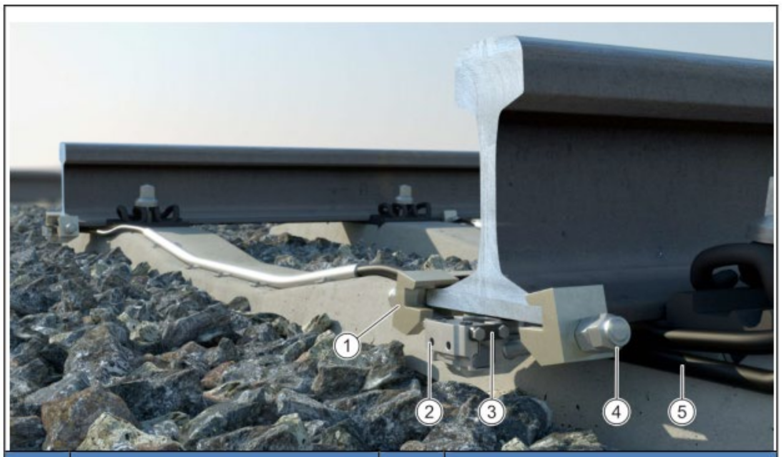
(b)

(c)



(d)

Figure 2.1 (a) Wheelscan1 detector by Schenck. Photo by Matthias Asplund, Trafikverket. (b) Positions of rail accelerance measurements within, and adjacent to, the Wheelscan1 detector at Sunderbyns sjukhus [6]. (c) Impact hammer and accelerometer [6]. (d) Measured rail accelerance and coherence at selected positions.



Item	Description	Item	Description
1	Sensor clamp	4	Lock nut
2	Sensor	5	Fibre optic sensor cable to FOC box
3	Sensor locking plate		

(a)

(b)

Figure 2.2 Fibre optic sensor installed under the rail of a zentrak detector. From [7].

3.2 Regulations on placement of wheel impact load detectors

As the placement of a detector has a significant impact on the quality and accuracy of the measurements, as well as on delays in railway operations as a consequence of an alarm, Trafikverket has specified requirements and recommendations to be considered when the location of a new WILD is selected, see [8]. The choice of the detector location made by Trafikverket needs to be approved by the producer of the detector.

In order to minimise delays due to alarms, the detector needs to be placed between two stations or railway yards that include side tracks (passing siding) and a road connection. In this way, the damaged vehicle can be shunted and maintained without affecting other railway operations, and the maintenance personnel and equipment can easily reach the vehicle. It is considered very important that the detector is placed in a location where the track is as flat and straight as possible, and where the vehicle is not in hunting motion, accelerating or decelerating. For these reasons, the detector needs to be placed at least 200 m from the nearest curves in a straight track section where trains do not brake or accelerate because of nearby signals, and where the vehicle speed is higher than 30 km/h. Locations where snow tends to accumulate on the track shall be avoided and the track slope may not be too large to risk wheel sliding. No transition curves, switches, crossings, bridges, faulty sleepers or rail joints may be closer than 150 m from the detector. Within a distance of 50 m from the detector, no thermite welds and no rail surface defects are allowed. In the vicinity of the detector, the deviation from nominal track gauge (1435 mm) may vary between +3 mm and -2 mm, the track cant may not exceed 2 mm, the sleeper deflection due to train passage may not exceed 10 mm, and the minimum compressive stress of the soil is 60 MN/m^2 [8].

3.3 Maintenance of wheel impact load detectors

In accordance with recommendations issued by the detector manufacturers, WILDs should be maintained once a year [9]. Moreover, the status of the track (in terms of track stiffness, track geometry, presence of surface defects) around the detector should be carefully checked during planned track maintenance.

For the Wheelscan detectors, maintenance needs to performed between June and August. The voltage of the electrical equipment is checked at a series of measurement points. The absence of defects and cracks is checked for the cables, instrumented sleepers, measuring equipments and junction boxes. For the latter, the absence of humidity is controlled, as well. The positions of the sleepers are checked and adjusted if these have moved more than 30 mm. The insulation and the resistance of the strain gauges and of the weighing beams are checked, as well as the measurement output signal. This is done using a tool provided by Schenck. The capacity of the batteries is measured, and the batteries are replaced if needed. After the maintenance procedure is completed, the technicians need to control that the measurement information from the first train passage is stored correctly in the system [9].

The zentrak detectors are maintained annualy between April and November. The scheduled maintenance procedure consists of a general inspection of the hardware and cabling status as well as cleaning and adjusting of the filters and optical sensors. The status of the sensors can be checked remotely using a tool provided by voestalpine. Moreover, condition based maintenance of zentrak detectors can be performed when inconsistent/lacking data or error messages are received. In these cases, maintenance actions can be completed with either a remote or an on-site visit according to the recommendations in the zentrak site assistant dashboard [10].

The technicians in charge of each maintenance check must report all faults that were found during the inspection, regardless of whether the WILD is of Wheelscan or zentrak type. They must also confirm that all the faults that were reported during the previous inspection have been fixed.

3.4 Calibration and verification of detector data

The calibration of each Wheelscan detector is performed on a service computer or directly at Schenck's headquarters in Darmstadt, Germany. There, calibration coefficients for the strain gauges are computed based on a series of test runs performed in both running directions at the location where the WILD has been installed using a train consisting of wagons with different axle loads. The train should run at all speeds in the designated speed range, e.g. from 20 km/h to 200 km/h in intervals of 10 km/h [5]. This, however, only allows for a calibration of the measured static loads. A procedure for the calibration of dynamic load has been developed at a later stage. It includes a freely falling weight of 25 kg that makes impact with the rail in the detector. However, this procedure cannot account for the influence of the quasi-static load due to the passing of the train and is therefore not optimal for the calibration of dynamic loads measured in operational conditions.

To calibrate the zentrak detectors, an external calibration device is needed. Calibration needs to be performed when the detector is installed. Moreover, since the speed indication, the train recognition and the calculation of the axle distances of trains depend on the correct sensor distance, the distance between sensors needs to be carefully verified. Once the sensors have been mounted correctly, the system starts a continuous calibration process with passing trains. Additional calibrations are therefore not required [10]. A procedure for the calibration of dynamic loads measured by zentrak detectors has not been developed or unveiled yet.

In order to maximise the availability of the detector systems, the detector suppliers are required to verify the quality of detector data output every other week. The procedure is based on the guidelines written by the supplier technical support. After each analysis, the supplier has to file a list describing the analyses they have performed, and (if needed) the actions they have taken and their suggestions for improving the status of the detector [9].

As part of the procurement process of new wheel flat detectors in 2006, extensive field testing was carried out by Banverket [11]. The Track Loading Vehicle (TLV) was used to apply different forms of excitation in the form of a cosine ramp (0.5 Hz), swept sine (1 – 20 Hz and 10 – 200 Hz) and random noise (10 – 100 Hz) excitation. Further, a sledgehammer was applied for impulse excitation up to 1000 Hz. Based on this testing, it was concluded that the Schenck detector was approved for weighing and for detecting wheel flats according to the technical specification of requirement. However, it was also stated that the detector was not accurate for frequencies around 350 Hz. Thus, a dynamic calibration of the detector, and frequency compensation by a proper digital filter for each sensor in the detector, was recommended.[2]

Trafikverket is currently engaged in developing diagnostic procedures aimed at monitoring detector data and enabling the automatic detection of faults. The manual identification of detectors requiring recalibration or replacement is a time-consuming process, demanding large volumes of data that can only be processed for one device at a time. Furthermore, the analysis and interpretation of this data often rely on the subjective expertise of technical specialists. The design of the automated diagnostic procedure for wheel impact load detectors is based on data derived from locomotive passages. This approach is effective because locomotives, unlike passenger vehicles or freight wagons, maintain a constant mean load. The static loads measured from the axles of locomotives passing over the detectors over a month are compared to data from the national vehicle register (Fordonsregistret). Detectors are flagged if the expected measured values significantly deviate from the actual measurements, or if the variance in the results exceeds the expected variance defined by the detector manufacturer. Similar procedures are being designed for other devices (axle counters, RFID tag readers, temperature sensors, etc.).

3.5 Trafikverket's plan for future detector installations

Trafikverket's choice of detector types, the priorities regarding the locations where new detectors should be installed, and the strategy regarding the replacement of older detectors are based on the research that was performed in the project D-RAIL [13], which aimed at reducing the number of occurrences and consequences of derailments.

According to the research performed in D-RAIL, axle ruptures and failures of wheels and bearing boxes are among the primary causes of derailments of freight trains. Uneven loading of wagons, faults in the primary suspension and rail breaks are also frequent causes, but not to the same extent as the aforementioned ones. For this reason, Trafikverket has prioritised the installation of hot wheel detectors and hot axlebox

---

[2] During the same procurement process another detector named BAAS was also tested using the TLV and impulse excitation. This detector measured rail bending. It was approved for detecting wheel flats according to the technical specification of requirement, but not approved for weighing [12].

detectors in its network. These can respectively detect faults in brake systems (brakes that lock on the wheels causing them to slide on the rails) and in bearing boxes. In the long-term, the aim is to install a hot axle box and hot wheel detector (HABD) with a maximum distance of 70 km between installations on single track, and with a maximum distance of 50 km on double track (and approximately every 40 km for the Iron Ore line).

WILDs are instead less frequent throughout the network. They can be used to detect skew loading of wagons, but it is often not possible for train operators to redistribute the loading of a wagon if no appropriate facilities are present in the vicinity. WILDs are instead more useful to detect anomalies in wheel–rail contact forces due to issues with suspensions, dampers and wheel out-of-roundness. These are expected to cause less derailments than hot wheels and hot axleboxes but can still contribute to the degradation of the infrastructure.

Trafikverket plans to increase the number of WILDs in the long term (although these will still be less frequent than hot axlebox or hot wheel detectors). All the Wheelscan detectors will be replaced by zentrak detectors in a twelve-year period, starting from the older generation Wheelscan1. When a detector is replaced, its position is changed in case the original location did not match the most significant requirements in [8] and if a more optimal location can be found in the vicinity. There are plans to install more WILDs in the future. The possibility to adopt completely new types of detectors (such as wheel profile detectors) is being investigated, as well.

4 Influence of wheel damage and traffic conditions on wheel impact loads

4.1 Case study 1: Analysis of wheel impact load detector data

An analysis has been carried out by extracting data from six Schenck WILDs positioned between Luleå and Borlänge along the route for the so-called *Stålpendeln*, see the MSc thesis project carried out by Klara Mattsson [14]. The route is used by the freight traffic operator Green Cargo AB to haul steel slabs on commission for the Swedish steel company SSAB. The maximum allowed axle load on the line is 25 tonnes. Data from the detectors were collected from December 2022 to March 2023.

The analysis started by examining a document containing information about wheel replacements in the workshop in Luleå. The document included information about when and for what reason a wheel was replaced. If the reason for replacement was a wheel flat, the length of the non-rounded part of the wheel flat had been measured in the workshop before wheel turning. As measurement of wheel flat length is notoriously difficult, flat lengths had generally been rounded up to the nearest 5 millimetres. For each detected wheel flat, data from the six WILDs was compiled for the corresponding wagons and the studied time period. The date of discovered damage that was stated in the document from Luleå was used as a starting point to manually find in between which two detectors the wheel flat was generated by comparing measured loads in the WILD database. In total, 823 detector passings by 149 different wheelsets (with at least one of the wheels on the axle being defective) were included in the analysis. Figure 4.1 illustrates an example of how four data points were extracted from the database.

All data from passages at train speeds below 40 km/h were filtered out since the RFID tag used for identifying wheelsets was not considered accurate for those speeds. Only the highest peak load per axle and detector passage was included in the analysis. The wagons in the analysis were either loaded or unloaded. The analysis of unloaded wagons consisted of wagons with axle loads in the interval 4.5 – 6 tonnes and speeds between 69 and 120 km/h. The number of detector passages with unloaded wagons was 645. The loaded wagons, on the other hand, had a range of axle loads between 17 and 25 tonnes and speeds in the interval 64 – 90 km/h. The number of detector passages for the loaded cases was 159. Figure 4.2 illustrates a summary of peak loads for all detector passages included in the analysis. Note that the blue line indicates the warning levels issued by Trafikverket. It is observed that most warning alarms were generated by unloaded wagons in the form of ratio alarms for wagons with axle loads of around 5 tonnes.

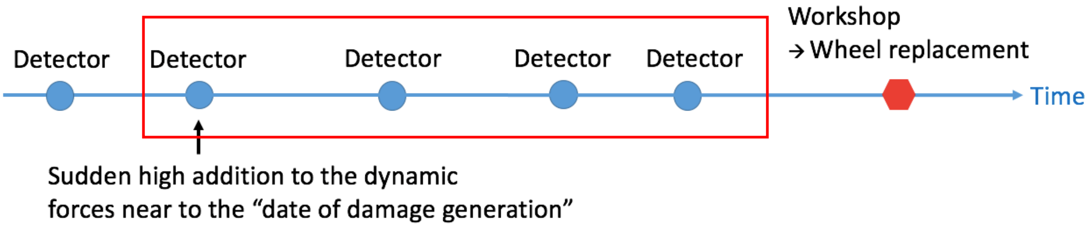


Figure 4.1 Timeline describing the approach used to extract detector data to be included in the analysis. In this example, data from four detector passages by the same wheelset were selected for the analysis. From [14].

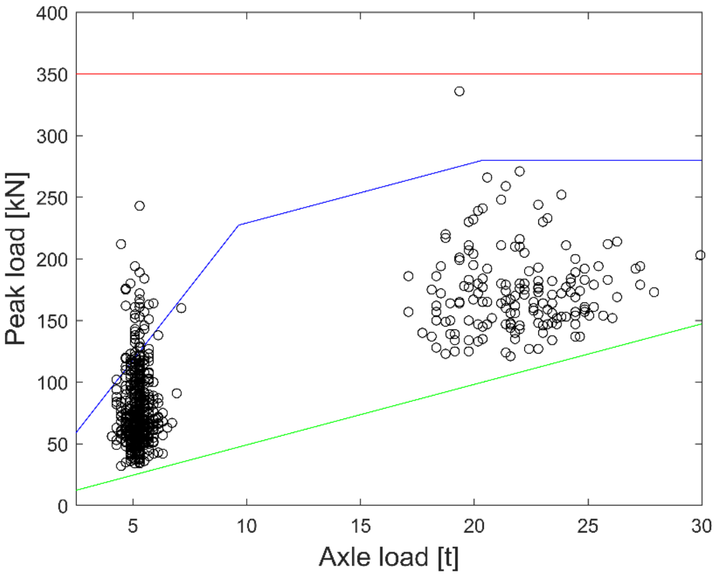


Figure 4.2 Influence of axle load [tonnes] on measured peak load for all 823 analysed detector passages. The red line is the 'high' alarm at 350 kN. The blue line indicates warning levels set by Trafikverket in terms of ratio (axle loads up to 10 tonnes), dynamic load (axle loads in the interval 10 – 20 tonnes) and peak load. The green line illustrates the relation between mean load and axle load. From [14].

4.2 Case study 1: Influence of wheel flat length and train speed

For different intervals of wheel flat length, and for loaded and unloaded wagons, Figures 4.3 and 4.4 present the influence of train speed on measured peak loads. A linear regression has been made in each subplot to indicate any possible trend in the data, but as the R^2-value (coefficient of determination) is generally very low this could not be confirmed. In some of the subplots, the number of data points is very small. Nevertheless, based on this dataset, there seems to be no evident increase in peak load with increasing train speed for any of the wheel flat length intervals. This is an unexpected result.

In each subplot, each colour represents one specific wheel flat. Thus, if the same colour is repeated several times, this means that the same wheel flat has passed several detectors. For the two wheels on an axle, the highest peak load was extracted from each detector passage. Thus, the same colour could potentially represent either the left or the right wheel on the same axle. As mentioned above, wheel flat lengths were measured in the workshop before the wheels were turned. Figures 4.5 and 4.6 show the same data, but in this case for different intervals of train speed. Although the scatter in data is again very significant, an expected trend indicating higher peak loads with increasing flat length can be distinguished in most subplots.

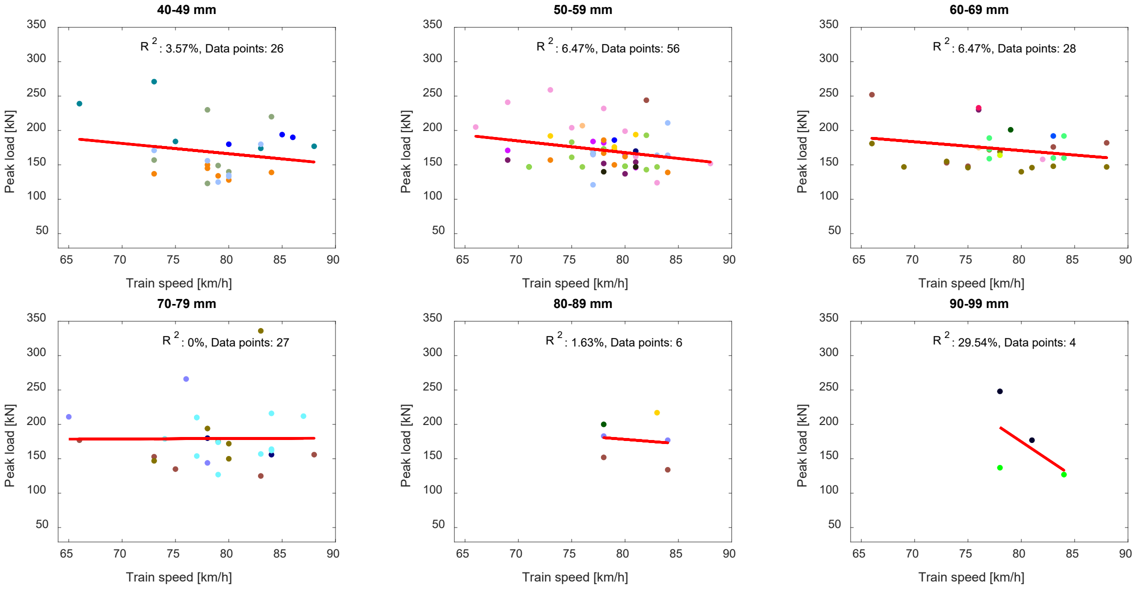


Figure 4.3 Influence of train speed on measured peak loads: different wheel flat length intervals, loaded wagons with axle loads 17 – 25 tonnes. From [14].

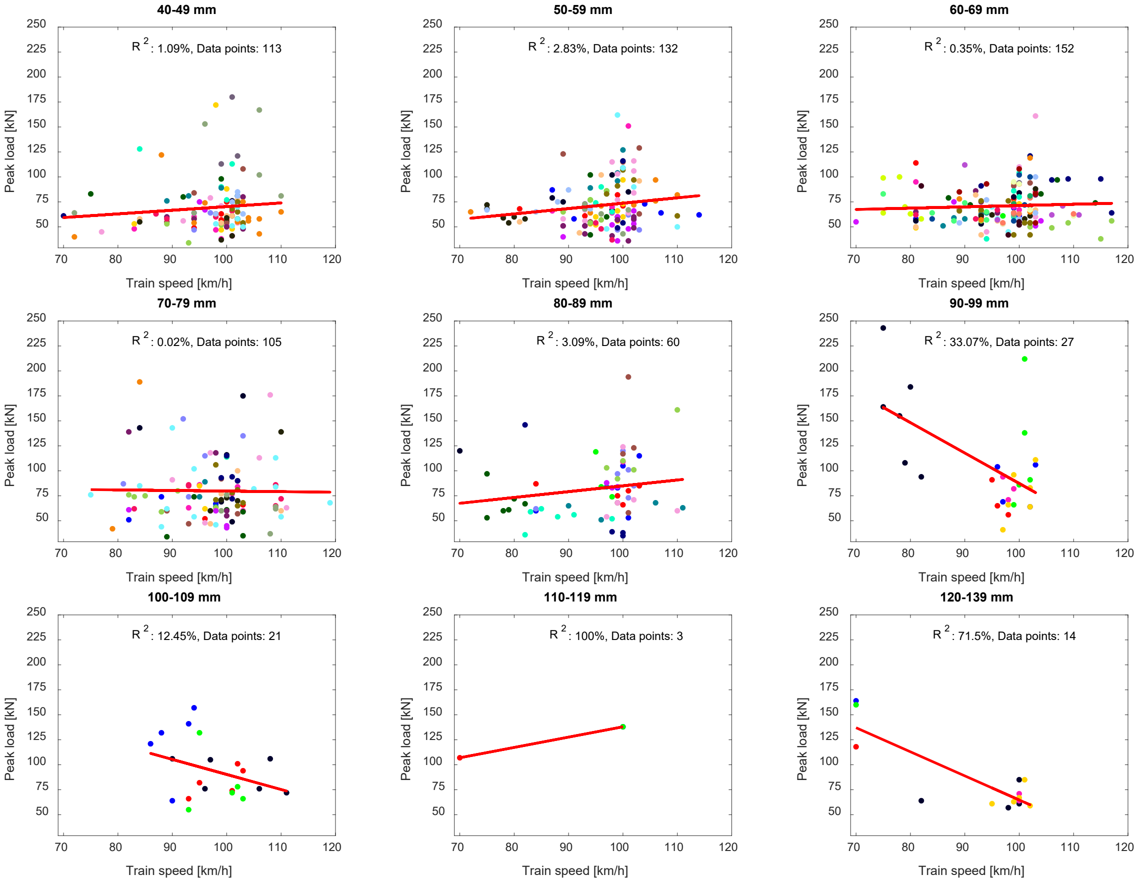


Figure 4.4 Influence of train speed on measured peak loads: different wheel flat length intervals, unloaded wagons with axle loads 4.5 – 6 tonnes. From [14].

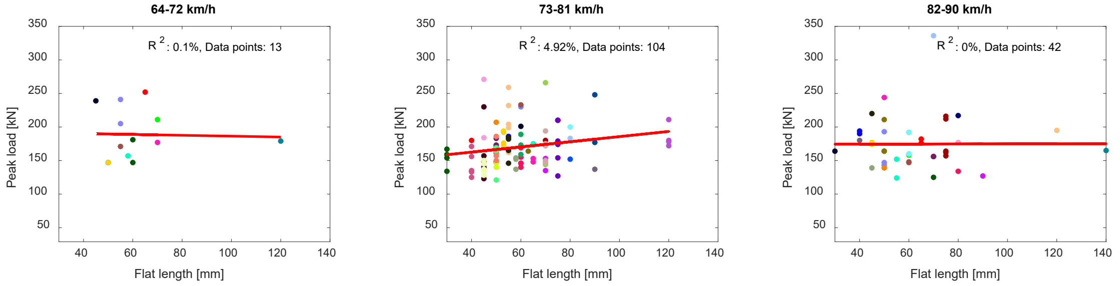


Figure 4.5 Influence of wheel flat length on measured peak loads: different train speed intervals, loaded wagons with axle loads 17 – 25 tonnes. From [14].

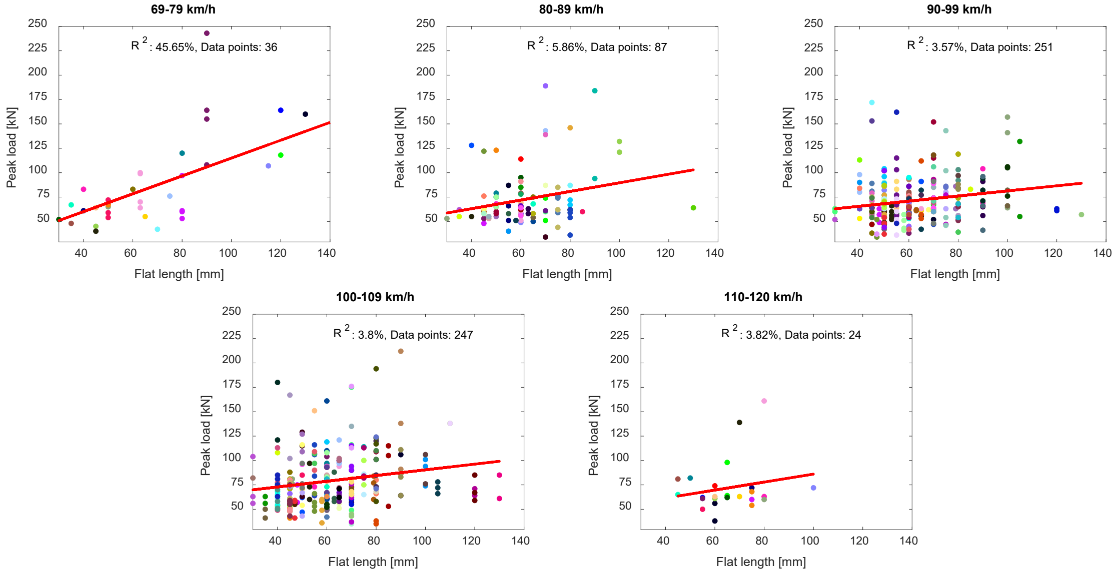


Figure 4.6 Influence of wheel flat length on measured peak loads: different train speed intervals, unloaded wagons with axle loads 4.5 – 6 tonnes. From [14].

There are several potential reasons for the large spread in the data. One reason could be differences in lateral wheel contact position relative to the position of the wheel flat while passing over the different detectors. For example, in one detector the contact position on the wheel might have been well aligned with the centre of the flat (with the maximum depth), while in another detector the wheel–rail contact might have occurred towards (or even outside of) the inner or outer edges of the flat. Based on simulations of dynamic vehicle–interaction with wheel flats, it can be shown (not shown here) that the significance of wheel flat depth on the generated impact load is larger than the corresponding significance of flat length. However, the measured wheel flats may have had rounded edges, and the depths of the flats are unknown. Other reasons could be related to differences in the position within a sleeper bay where the flats made impact with the rail. Differences in wheelset design, differences in wheel radius and unsprung wheelset mass due to wear, as well as variation in track stiffness between different detectors and irregularities in track geometry, are other factors contributing to the scatter in data.

Figure 4.7 presents the cumulative distributions of peak load for the same data as in Figure 4.3. The red line indicates the 'high' alarm limit of 350 kN, while the orange dashed line is the warning level 280 kN set by Trafikverket. In summary, based on the 823 investigated detector passages with wheel flats of different lengths, there was no case of peak load exceeding 350 kN. This was unexpected since several of the investigated cases involved wheel flats significantly longer than 60 mm.

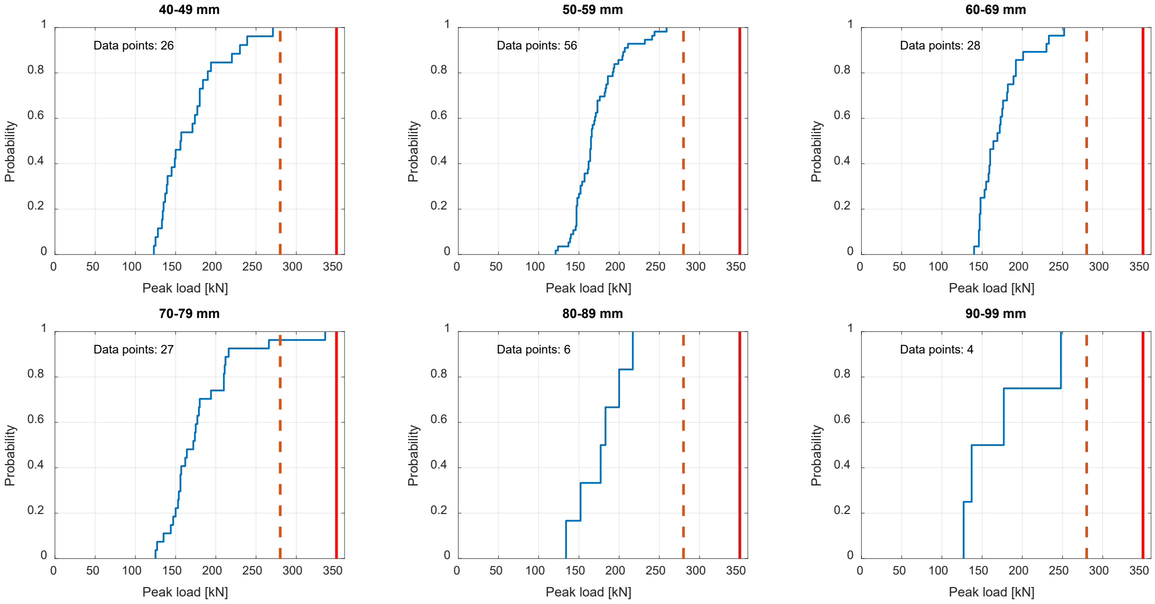


Figure 4.7 Cumulative distributions of peak load for different intervals of wheel flat length: loaded wagons with axle loads 17 – 25 tonnes. From [14].

4.3 Case study 1: Measured loads for a given wheel flat in several detectors

For a given 75 mm wheel flat among those studied in Sections 4.1 and 4.2, all registered peak loads and mean loads in six different WILDs along the route for Stålpendeln have been studied, see Figure 4.8. The presented data covers the period from when the flat was generated until the wheelset was taken out of service for repair. Two journeys in loaded conditions and three journeys in tare conditions are considered. A large variation in measured loads between different detectors during a given journey is observed. Further, a clear pattern in how the detectors measured relative to each other is noted, see for example differences in data from the detectors at Degerbäcken and Skorped. This indicates that besides the variation in speed and other influencing variables, the condition of the detectors might have affected the measured loads. For example, the time since calibration and measurement accuracy may vary between the individual detectors. Unfortunately, time histories from each wheel passage in the different detectors and the routine for post-processing of data are not available for a more detailed analysis of the measured loads.

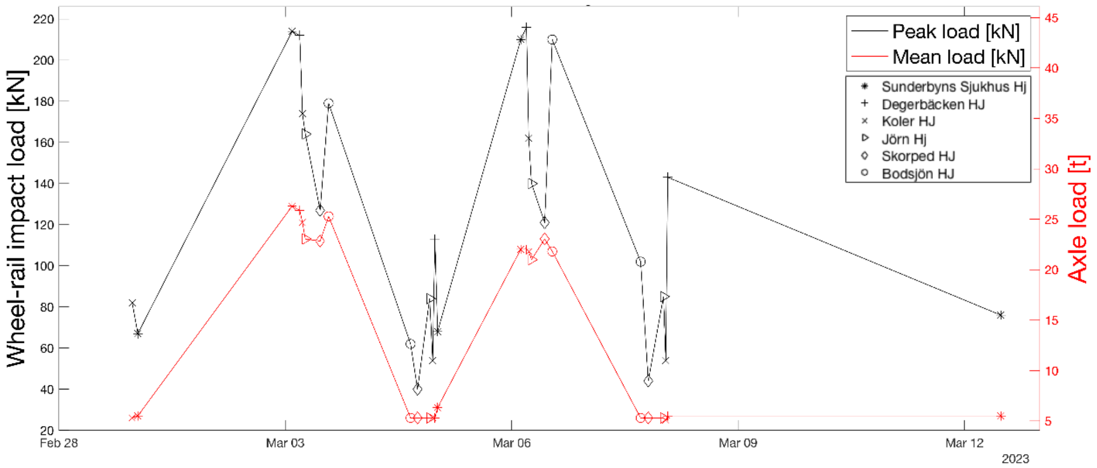


Figure 4.8 Peak loads and axle loads for one given wheel flat with length 75 mm measured in six WILDs along the route for *Stålpendeln*. From [14].

4.4 Case study 1: Analysis of detector status – mean loads

According to regulations set by Trafikverket, measured mean loads for locomotives should be within a tolerance of ± 5%. The accuracy of mean loads measured in the detectors at Degerbäcken and Skorped have been assessed by collecting measured loads from the Transmontana CoCo locomotives that are used to pull the *Stålpendeln* wagons. For each wheelset, the mean loads of both wheels on the same axle were summed and divided by the nominal axle load of the locomotive. Note that the nominal weight (125 tonnes) of the locomotive may vary during the winter due to accumulation of ice in the bogies. The evaluated ratios between mean load and nominal axle load are presented in Figure 4.9. A linear regression has been made based on all data in each plot. For both detectors, it is observed that the measured loads for axles 2 and 5 are consistently lower than for the outer axles in each bogie. Nevertheless, it is argued that the measurement accuracy (in terms of mean load) of the detector at Degerbäcken is considerably higher than for the detector at Skorped.

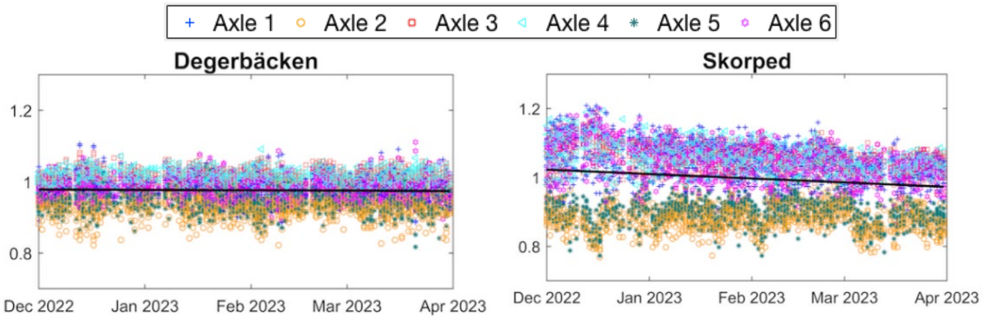


Figure 4.9 Ratio between measured mean load and nominal axle load for Transmontana CoCo locomotives. WILDs at Degerbäcken and Skorped.

4.5 Case study 1: Analysis of detector status – track geometry and stiffness

In parallel, track foundation stiffness and track irregularities in the detectors along the route for *Stålpendeln* have been measured by track recording cars [15,16], see Figures 4.10 to 4.13 and the Appendix.

For the WILD at Degerbäcken, it was found that the measured vertical track stiffness is very low but relatively uniform, see the upper plot in Figure 4.10. The longitudinal level and alignment are within the tolerance limits proposed here (cf. the caption to Figure 4.10), see middle and lower plots in Figure 4.10. According to SGU (Geological Survey of Sweden), the low track stiffness at Degerbäcken is due to that the detector has been placed on top of a peat layer. There are some irregularities in the gauge but within the tolerance limit specified in TDOK 2013:0689, see the upper plot in Figure 4.11. However, the cross level exceeds the tolerance limit, see the middle plot in Figure 4.11. The detector is placed on tangent track (very small curvature), see the lower plot in Figure 4.11.

On the other hand, it is observed that the WILD at Skorped has irregularities within the detector area both in terms of track stiffness (although at much higher magnitudes), longitudinal level, alignment and cross level. In particular, the cross level exceeds the tolerance limit. Irregularities in track geometry could affect the vehicle dynamics while passing through the detector. The corresponding figures for the detectors at Sunderbyn, Koler, Jörn, Bodsjön, Mellansjö and Hållsta are presented in the Appendix. Note that the detector at Mellansjö is placed in a short tangent track section between two curves, see Figure A10. In summary, the calibration of the detectors, as well as the measured variations in track stiffness and track geometry at the detector sites might have contributed to the scatter in measured peak loads.

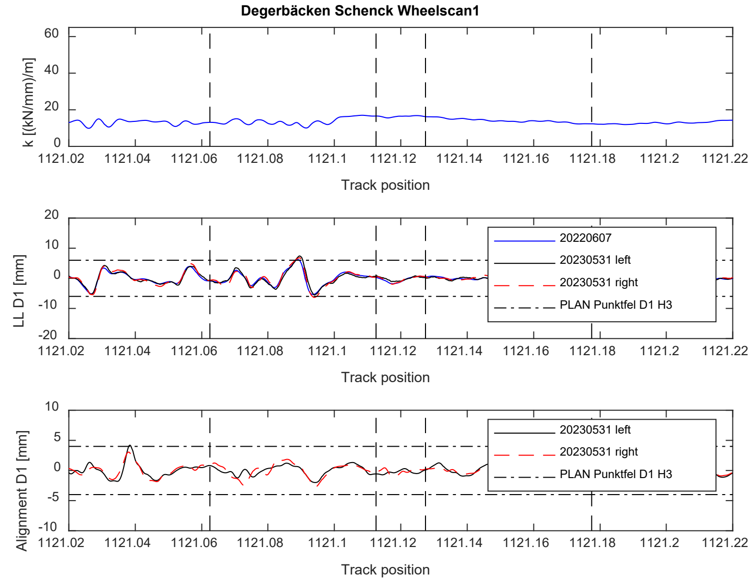


Figure 4.10 Foundation stiffness, longitudinal level (bandpass filtered 1 – 25 m) and alignment (1 – 25 m) measured over a distance of 200 m in the WILD at Degerbäcken. Blue curves were measured on 2022-06-07. Black (left rail) and red (right) curves were measured on 2023-05-31. The inner pair of vertical lines indicates detector area 1 (15 m), while the outer pair of vertical lines indicates detector area 2 (50 m on either side of detector area 1). Horizontal dash-dotted lines indicate suggested tolerances in terms of planned maintenance for tracks with maximum allowed speed up to 160 km/h. From [15].

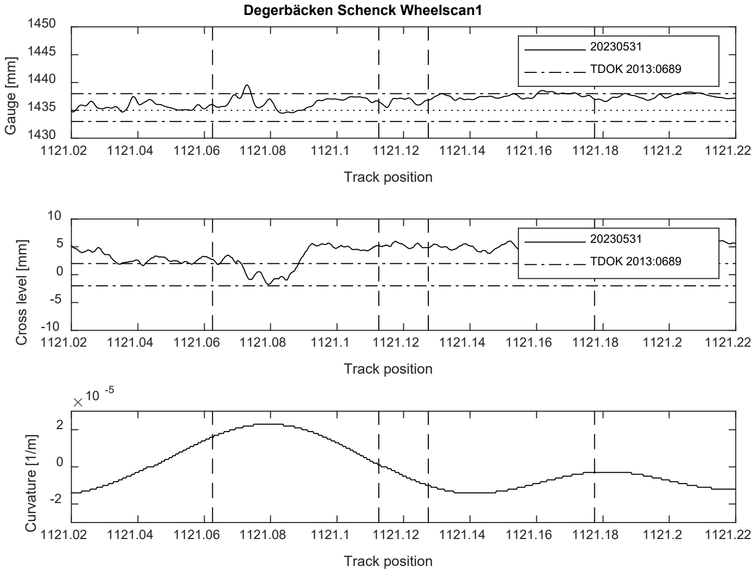


Figure 4.11 Gauge, cross level and curvature over a distance of 200 m in the WILD at Degerbäcken. The inner pair of vertical lines indicates detector area 1 (15 m), while the outer pair of vertical lines indicates detector area 2 (50 m on either side of detector area 1). Horizontal dash-dotted lines show tolerance limits according to TDOK 2013:0689. From [15].

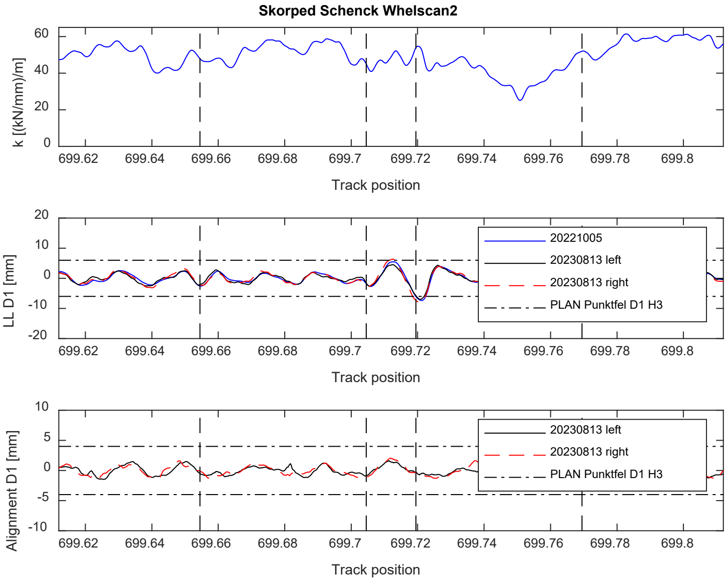


Figure 4.12 Foundation stiffness, longitudinal level (bandpass filtered 1 – 25 m) and alignment measured in the WILD at Skorped. Blue curves: 2022-10-05. Black and red curves: 2023-08-13. See also caption to Figure 4.10. From [15].

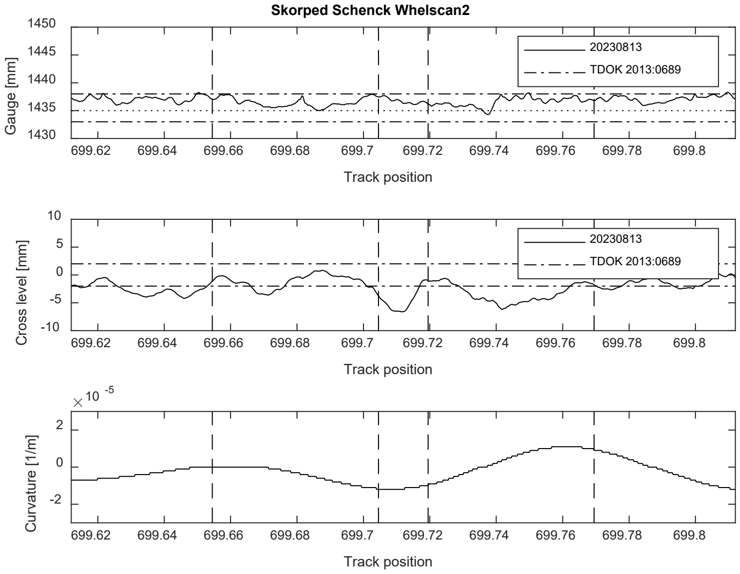


Figure 4.13 Gauge, cross level and curvature over a distance of 200 m in the WILD at Skorped. See also caption to Figure 4.11. From [15].

5 Consequences of wheel damage – Trafikverket

The aim of Trafikverket's network of detectors is to prevent failures and abnormal degradation of the railway infrastructure due to faulty vehicles. Detectors can discover faults on the vehicle that may lead to derailments and/or damage to the vehicle itself, to the track, as well as to the catenary system. Thus, they improve the safety and robustness of the railway system, and they reduce the risk of delays for passenger and freight vehicles.

Trafikverket provides a service named "teknisk kontroll av fordon" (technical control of the vehicle), which allows train operators to receive raw data registered for a given train by all the detectors in the Swedish network. Data are updated in real time, including issued warnings or alarms. This helps the train operators to have better control of the status of their fleet during service.

Vehicles, in particular freight wagons, tend to trigger different WILD responses depending on the type of bogie, see Section 6.

Kvar att göra: Kristoffer Kraft återkommer med analys av inverkan av olika boggityper och fordonstyper.

5.1 Rail breaks

Rail breaks due to high mechanical stress in the material is a severe form of damage that can be caused by abnormal traffic conditions, extreme wheel loads, as well as triggered by manufacturing defects. Low temperatures increase the risk for rail breaks since cold temperatures increase the tensile stresses in continuously welded rails. Rail breaks significantly increase the risk of derailment.

Rail damage is defined by Trafikverket [17] as:

- Rail breaks: rails that break in two or more pieces, resulting in an area of missing material on the track which is at least 50 mm long and 10 mm deep
- Cracked rails: rails presenting one or more visible or invisible cracks that can grow to cause a rail break
- Damaged rails: rails presenting forms of damage that are not rail breaks or cracks

Trafikverket performs scheduled ultrasound tests of rails to detect damage. Every fault needs to be reported to prevent rail breaks.[3]

High impact loads due to damaged wheels can initiate rail cracks or trigger the propagation of existing rail cracks. Rail breaks occurring directly after a high impact load from a damaged wheel are rare but have occurred in the Swedish network. In February 2019, a freight train caused two rail breaks between Boden and Sävastklinten [18]. One of the rail breaks occurred at a thermite weld spot beside a switch. The other one occurred from the foot of a straight piece of rail exactly above a sleeper edge. One wagon in the freight train that caused the break had two damaged axles. The first wheelset had a 180 mm long wheel flat on each wheel. The second wheelset had a 190 mm long and 8.5 mm deep flat, as well as a total of 23 damaged spots on the wheels,

---

[3] Eddy current tests are not performed during scheduled maintenance.

where 13 of these were wheel flats with a length of more than 60 mm. The nearby WILD in Sunderbyn was out of service, but simulations indicated that such forms of damage could cause impact loads between 570 and 630 kN, depending on vehicle speed [18].

Trafikverket records information on the causes and consequences of each reported rail damage. In 2021, a requirement was introduced mandating that rail sections subjected to five or more instances of impact loads exceeding the high-level alarm 350 kN (425 kN for locomotives) should be subjected to ultrasound testing to detect potential track damage caused by these high loads. Since the introduction of this requirement, no maintenance warnings have been issued based on the ultrasound tests triggered by high-level alarms [19]. Consequently, this requirement was removed in 2024. In 2023, no rail breaks due to wheel flats or damaged wheels were reported [19]. This suggests that a 350 kN threshold may be an adequate fail-safe alarm level to prevent severe crack propagation and rail breaks, although this is also influenced by neutral and ambient temperatures.

Rail damage is one of the main causes of derailment, which causes further damage to the infrastructure as well as damage to the rolling stock, severe delays and in the worst cases injury to people.

5.2 Costs

Trafikverket uses accumulated hours of delay of trains to quantify the consequences of abnormal wheel–rail contact forces on the railway network. A method to convert hours of delay into a measurable economic cost is not yet available.

In general, a train which has been stopped or delayed because of a WILD alarm or warning generates more hours of delay if it is travelling in densely populated regions or in the vicinity of larger cities as railway traffic is heavier in these areas. Even though the amount of freight trains travelling in the Swedish network over one year is only one tenth of the amount of passenger trains, freight trains stand for double the amount of total hours of delay compared to passenger trains.

According to Trafikverket's statistics in 2023 [20], railway companies accounted for about 45000 hours of delay. Accidents/incidents and external causes, such as unauthorised people on the tracks, caused around 37000 hours, while infrastructure-related reasons amounted to roughly 23000 hours. Other reasons made up to 32000 hours of delay. Among these, inspections of vehicles or tracks (such as those occurring after alarm/warning levels) caused 1000 hours of delay in 2023, while they caused around 300 hours of delay in 2013. Thus, the total number of delay hours was in the order of 45000 + 37000 + 23000 + 32000 = 137000 hours.

6 Consequences of wheel damage – Green Cargo

6.1 Wheel load data

As described above, a WILD measures the static force, which is half of the axle load if the cargo is evenly distributed, as well as the maximum force the wheel has exerted on the track during the measurement interval. These measured values are referred to as the mean and peak loads.

Trafikverket's warning alarm is a service they provide. There are no restrictions associated with warning alarms from the WILDs. The driver is informed by the traffic controller about the axle number and side that set off the alarm. The intention is to prevent a future high-level alarm at stopping level. The limits for the warning alarms have been set by the operators. If the limits set by Trafikverket are exceeded, the train driver is contacted by traffic control, who informs the driver about the alarms triggered and any potential consequences. Only a high-level alarm can stop the train from continuing.

Many operators and vehicle owners subscribe to WILD measurement data from their vehicles. The purpose is to act before Trafikverket's limits are exceeded. There are certain conditions for this to work: The operator determines who should receive measurement data from a specific vehicle. Trafikverket then seeks consent from the various operators. Once this has been done, Trafikverket must be able to identify which operator was driving the train at the detector location. Challenges related to location and train direction exist. The vehicle's RFID tag must have been read, as the detector data recipients are linked to their individual vehicles. However, there are circumstances where no RFID tag reading is associated with any measurement data. The entire train may lack RFID readings despite having 'tagged' vehicles. This situation can occur when there is uncertainty about the number of axles on a particular train vehicle.

Other factors can also disrupt the connection to measurement data, the correct vehicle, and axle. This applies to vehicles not registered with the Swedish Transport Agency (Transportstyrelsen). Trafikverket retrieves axle count information from Transportstyrelsen's registry, and if missing, the detector makes an estimation based on measured axle distances. There have also been cases of 'overhearing' RFID readings from another train passing simultaneously on a different track. In such instances, the vehicle can be incorrectly associated with 100% corrupted data. If the RFID tag has been placed in an incorrect corner of the vehicle (as is the case for the rented Vectron locomotives), the measured data will be associated with the incorrect vehicle.

There have also been instances when a detector has stopped functioning and delivers obviously faulty data.

Assuming everything functions properly, subscribers receive measured values from the detectors and can take actions as needed. Additional data from the detector passage includes train number, speed, direction, ambient temperature, and how the vehicle was oriented in the train.

6.2 Number of trains stopped and delays

The number of alarms generated by steel shuttle wagons (Smmnps) in the detectors at Degerbäcken, Skorped, Mellansjö and Hållsta over the period from January 2020 to July 2024 is listed in Table 6.1. The data have been separated into bogie types Y25 and NACO. It is observed that both bogie types generated similar shares of alarms, although the NACO bogies had a somewhat higher share of ratio alarms (ratio > 4.8), while the share of peak alarms (285 kN) was slightly higher for the Y25 bogies.

The number of ratio alarms per thousand axle passages in each of the detectors at Degerbäcken, Skorped, Mellansjö and Hållsta is illustrated in Figure 6.0. Note that the detector at Hållsta was installed later than the other detectors. The detectors at Mellansjö and Hållsta have measured higher dynamic loads, and generated more alarms, than the detectors at Degerbäcken and Skorped.

For the detector at Mellansjö, it is shown that more alarms were generated in the summer of 2022 than during the winter 2021/2022. However, the winter 2023/2024 generated more alarms than the summer of 2023. Note that it has been confirmed by Roger Byström, Trafikverket, that the detector at Mellansjö had a software-related issue that was solved in March 2023. Further, from April 2023 and onwards, alarms not corresponding to peak loads > 150 kN, have been discarded resulting in a significant reduction of ratio alarms from Mellansjö.

The detector at Hållsta suffered from a hardware-related problem in early 2024. This was solved by the detector supplier and the detector returned to regular operation in 2024-03-26. It is argued that plotting the trends in generated alarms for many wheelset passages, as has been done in Figure 6.0, is an efficient approach to identify issues with the accuracy of the detectors.

Table 6.1 Number of alarms by Y25 and NACO bogies in the detectors at Degerbäcken, Skorped, Mellansjö and Hållsta over the period from January 2020 to July 2024. Both unloaded and loaded wagons.

Bogie type	Number of measured axles	Share of measured axles [%]	Number of ratio alarms	Share of ratio alarms [%]	Number of peak alarms	Share of peak alarms [%]
Y25	1 833 562	89	2 092	0.114	269	0.015
NACO	237 620	11	300	0.126	14	0.006

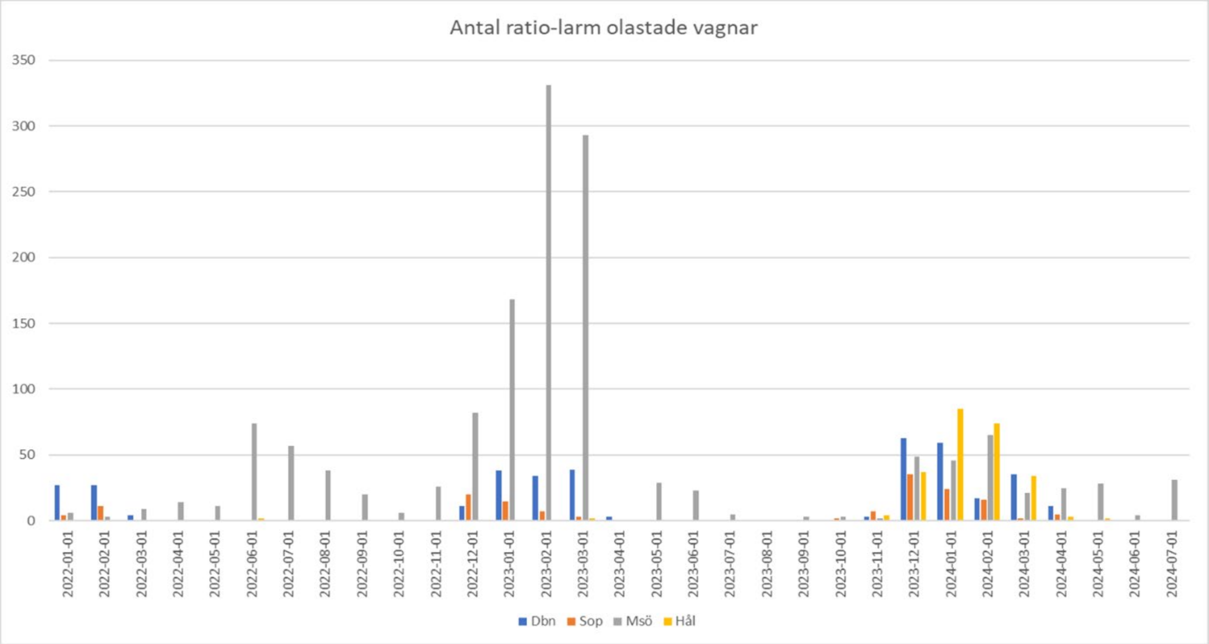


Figure 6.0 Number of alarms generated by both Y25 and NACO bogies in each of the detectors at Degerbäcken, Skorped, Mellansjö and Hållsta over the period from January 2022 to July 2024. Unloaded wagons.

6.3 Costs

The following paragraph exemplifies the costs imposed on Green Cargo in case of a detected wheel flat:

An incident occurred in Via where an unloaded wagon with a 50 mm wheel flat was stopped in the detector, resulting in accumulated costs of 80 000 SEK for Green Cargo. These costs included the hourly rate for two locomotives that were stationary for seven hours, energy and maintenance costs for a locomotive that retrieved the wagon from Sundsvall, and fees to the Swedish Transport Administration for the extra train. Additionally, there were hourly costs for the train drivers, rental costs for the wagon that was stationary in Via due to workshop capacity issues, and costs for a mobile patrol that inspected the wagon. Revenue losses and customer costs were not included, which can be significant. For example, a recent one-day train delay resulted in a missed revenue of 180,000 SEK. The Via detector is located approximately 70 km from the nearest workshop.

6.4 Case study 2: Long-term assessment of detector at Degerbäcken

For the unloaded steel shuttle wagons, data from the Schenck Wheelscan1 detector at Degerbäcken has been extracted from July 2020 to June 2024, se Figure 6.1. The corresponding data for the loaded steel shuttle wagons are shown in Figure 6.2. The data has been separated for the two bogie types existing on these trains. The Y25 bogie with cast iron tread brakes is the bogie type used in most of these wagons, cf. Figures 6.1(a) and 6.2(a), while the number of wagons with the NACO bogie using composite brake blocks is 22% of the wagon fleet.

It is important to recognize that the type of braking system has a substantial effect on the generated wheel roughness, where the cast iron brake blocks lead to a rougher surface of the wheel tread. Wheel roughness spectra have been measured and compared for different braking systems, see the Dutch study by Dings et al. [21]. Generally, cast iron tread brakes produce higher levels of roughness over all evaluated wavelengths,[4] with a peak in the roughness spectrum for wavelengths around 6 cm leading to higher dynamic wheel loads and rolling noise.

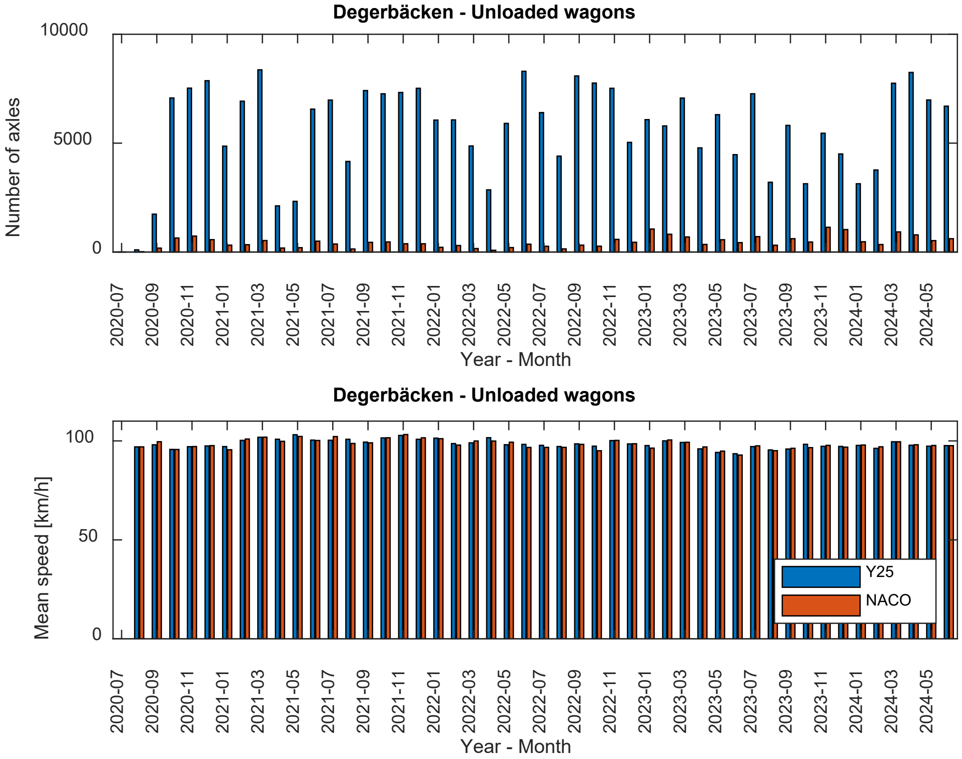
- The mean vehicle speed (evaluated over the period July 2020 – June 2024) of the unloaded and loaded Y25 wagons is 98.5 km/h and 81.7 km/h, respectively, see Figures 6.1(a) and 6.2(a). Considering the expected peak in the wheel roughness spectrum at 6 cm, this corresponds to excitation frequencies 450 Hz and 380 Hz, respectively.
- The mean axle load of the unloaded and loaded Y25 wagons is 5.0 tonnes and 21.5 tonnes, respectively, see Figures 6.1(b) and 6.2(b). The corresponding axle loads for the NACO wagons are very similar.
- The WILD at Degerbäcken seems to be consistent and accurate in terms of measured axle loads for the unloaded wagons. The recurrent small increase in axle loads each winter could be due to added weight from snow and ice.
- The Y25 bogies generate higher dynamic wheel loads than the NACO bogies, see Figures 6.1(c,d) and 6.2(c,d). This is expected considering the different types of braking systems. The mean dynamic loads for the loaded Y25 and NACO bogies (evaluated over the period July 2020 – June 2024) are 16.9 kN and 11.4 kN, respectively.
- There is a seasonal variation in measured dynamic loads with higher dynamic loads in the winter, see Figures 6.1(c,d) and 6.2(c,d). Considering the large number of wheel passings each month, particularly by wheels in Y25 bogies, and that the proportion of wheels with severe wheel tread damage should be relatively small (constituting mainly a few outliers in the data), it should be noted that the presented mean values are mainly affected by the consistent difference between braking systems and wheel roughness spectra, and not by the potential increase in number of wheels with severe wheel tread damage in winter.
- Based on the evaluated mean value per month, the dynamic loads measured on the left and right sides are similar in magnitude.

---

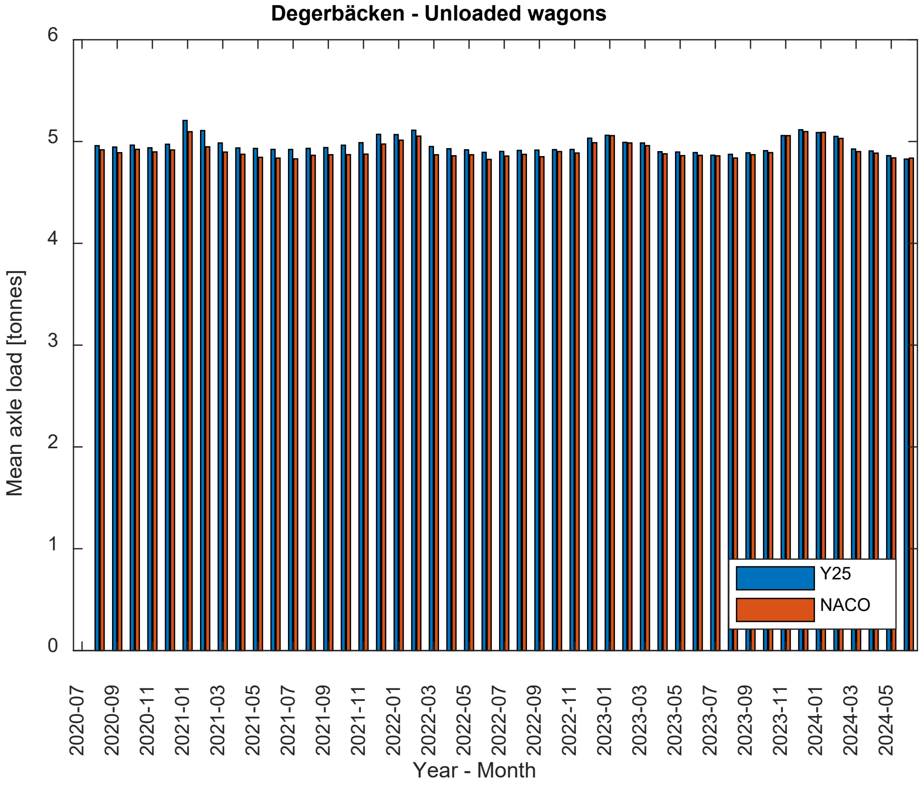
[4] Roughness level spectra are typically presented for wavelengths in the interval 1 – 31.5 cm.

- The dynamic loads generated by the loaded wagons are higher than the corresponding loads generated by the unloaded wagons, but the difference is relatively small, cf. Figures 6.1(c,d) and 6.2(c,d).
- Overall, the WILD at Degerbäcken seems to be working well. This is also expected as irregularities in track geometry and track stiffness are small, cf. Figures 4.10 and 4.11.

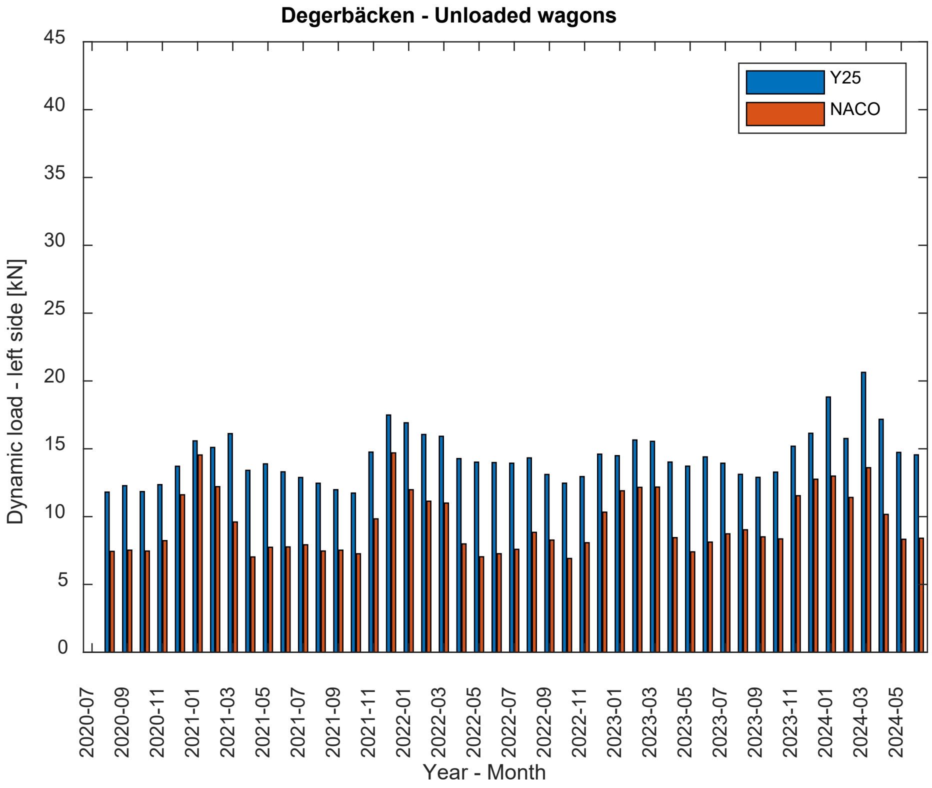
Similar long-term assessments of data from the detectors in Skorped, Mellansjö NSP, Mellansjö USP and Hållsta are reported below in Sections 6.5 – 6.8. Note that the same fleet of trains are passing the detectors at Degerbäcken, Skorped and Mellansjö. This means that any potential differences in measured axle loads and number of axle passages can only be explained by the measurement accuracy of the detectors and that sometimes a detector is closed for maintenance. However, the detector at Hållsta is on a different route. The number of detector data from Mellansjö NSP is small since most of the traffic is directed to the USP track.


Degerbäcken - Unloaded wagons
Number of axles
10000
5000
0
2020-07
2020-09
2020-11
2021-01
2021-03
2021-05
2021-07
2021-09
2021-11
2022-01
2022-03
2022-05
2022-07
2022-09
2022-11
2023-01
2023-03
2023-05
2023-07
2023-09
2023-11
2024-01
2024-03
2024-05
Year - Month
Degerbäcken - Unloaded wagons
Mean speed [km/h]
100
50
0
Y25
NACO
2020-07
2020-09
2020-11
2021-01
2021-03
2021-05
2021-07
2021-09
2021-11
2022-01
2022-03
2022-05
2022-07
2022-09
2022-11
2023-01
2023-03
2023-05
2023-07
2023-09
2023-11
2024-01
2024-03
2024-05
Year - Month

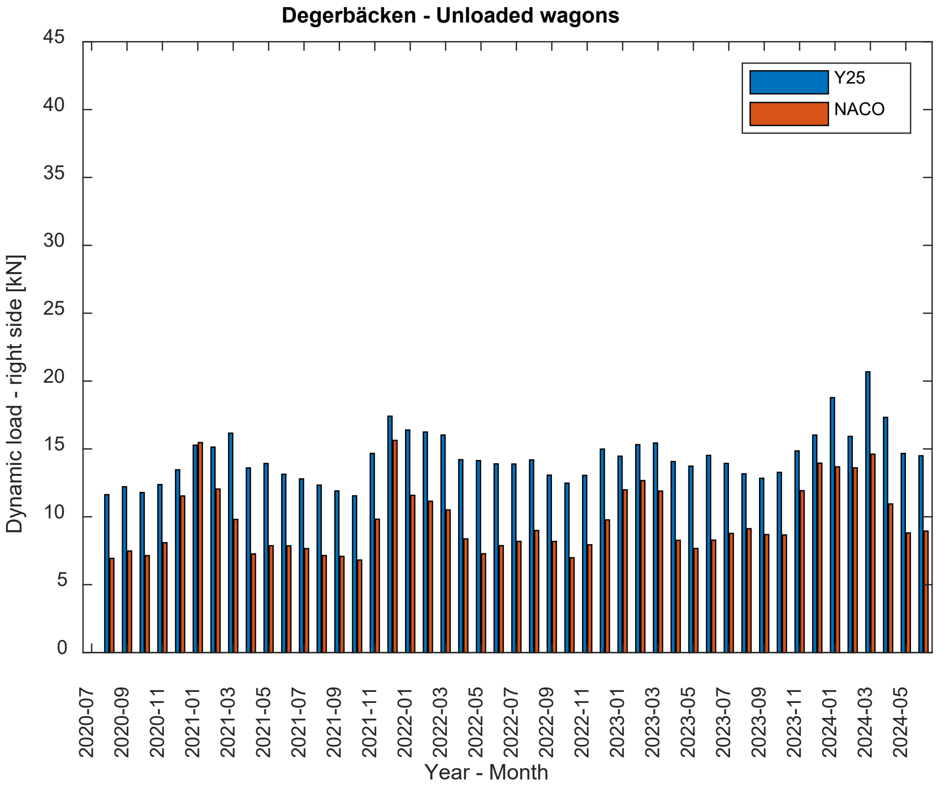
(a)


Degerbäcken - Unloaded wagons
Mean axle load [tonnes]
6
5
4
3
2
1
0
Y25
NACO
2020-07
2020-09
2020-11
2021-01
2021-03
2021-05
2021-07
2021-09
2021-11
2022-01
2022-03
2022-05
2022-07
2022-09
2022-11
2023-01
2023-03
2023-05
2023-07
2023-09
2023-11
2024-01
2024-03
2024-05
Year - Month

(b)

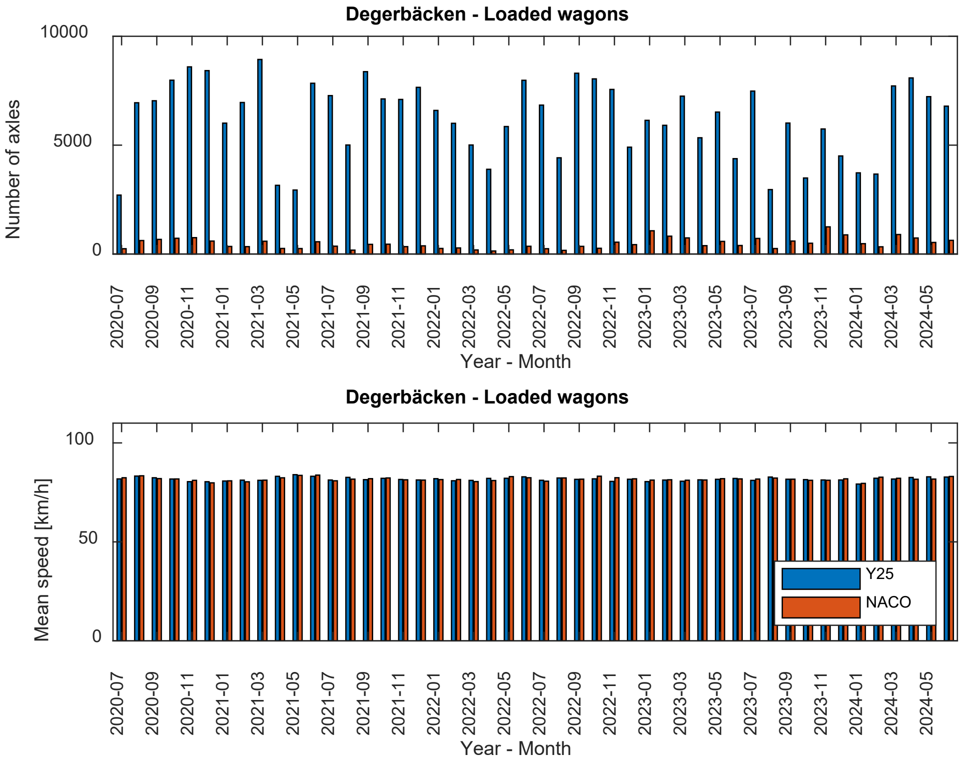


(c)

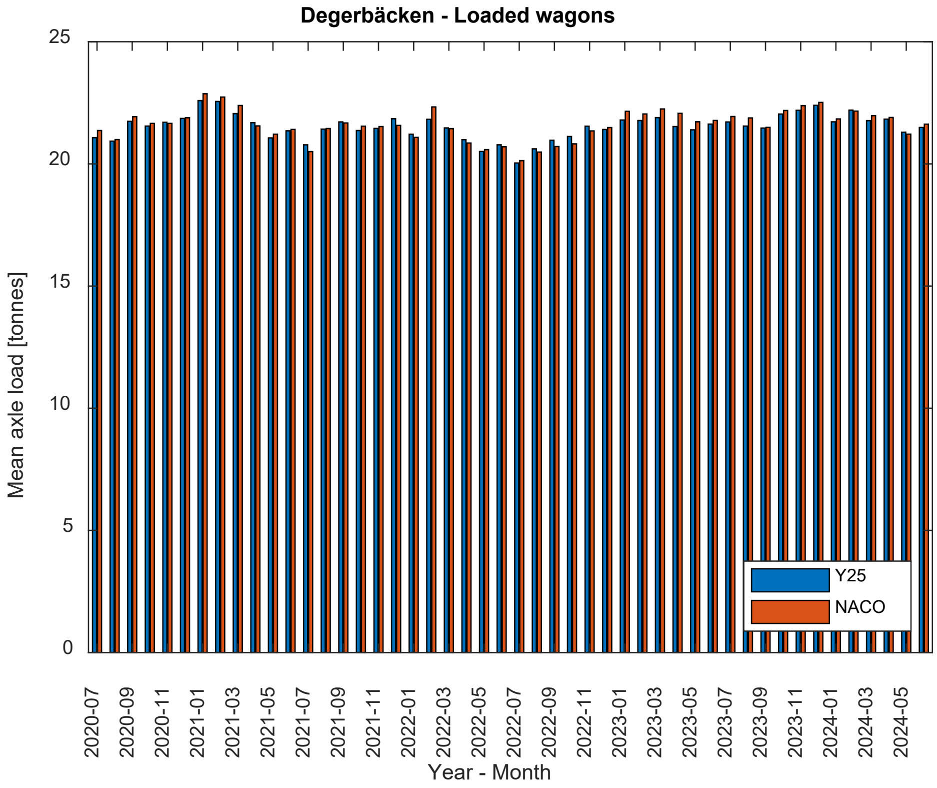


(d)

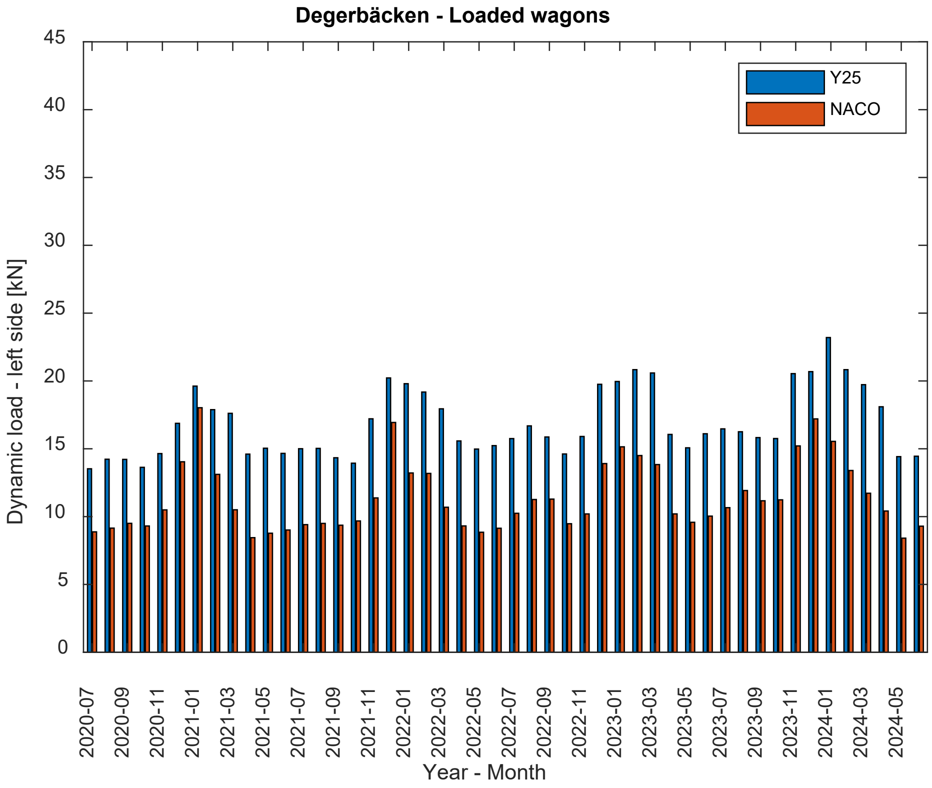
Figure 6.1 Long-term measurement in the Schenck detector at Degerbäcken – unloaded steel shuttle wagons: (a) Number of measured axles with either Y25 or NACO bogies, and mean vehicle speed. (b) Mean axle load. (c) Mean of dynamic loads per wheel – left side, (d) Mean of dynamic loads per wheel – right side.


Degerbäcken - Loaded wagons
Number of axles
10000
5000
0
Year - Month
2020-07
2020-09
2020-11
2021-01
2021-03
2021-05
2021-07
2021-09
2021-11
2022-01
2022-03
2022-05
2022-07
2022-09
2022-11
2023-01
2023-03
2023-05
2023-07
2023-09
2023-11
2024-01
2024-03
2024-05
Degerbäcken - Loaded wagons
Mean speed [km/h]
100
50
0
Y25
NACO
Year - Month

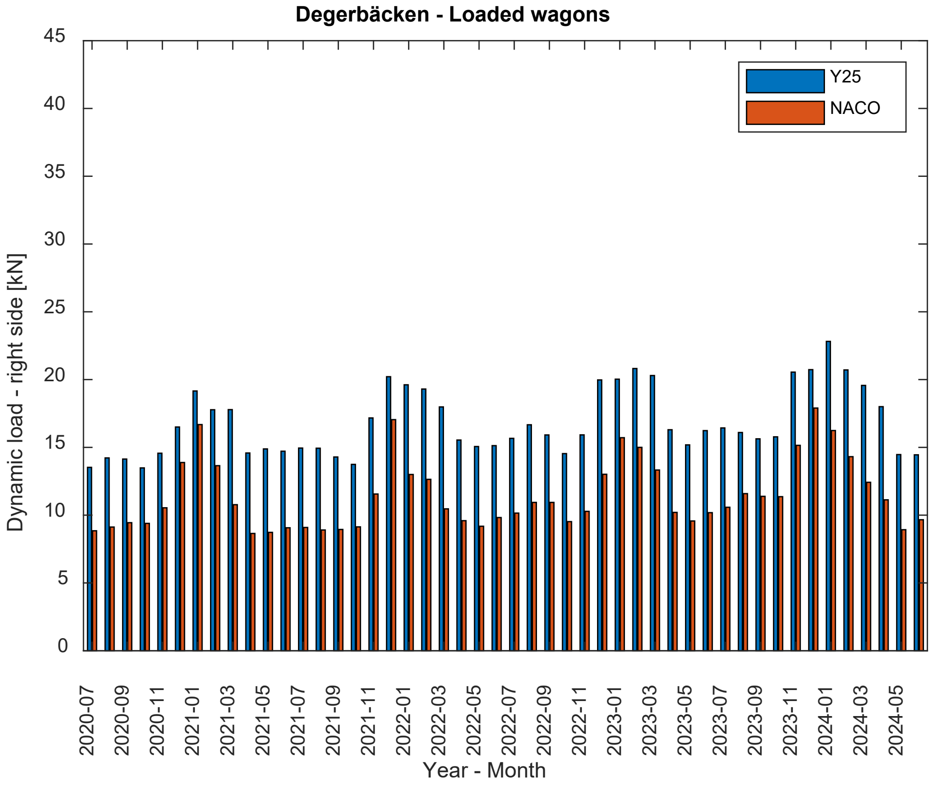
(a)


Degerbäcken - Loaded wagons
Mean axle load [tonnes]
25
20
15
10
5
0
Y25
NACO
2020-07
2020-09
2020-11
2021-01
2021-03
2021-05
2021-07
2021-09
2021-11
2022-01
2022-03
2022-05
2022-07
2022-09
2022-11
2023-01
2023-03
2023-05
2023-07
2023-09
2023-11
2024-01
2024-03
2024-05
Year - Month

(b)



(c)



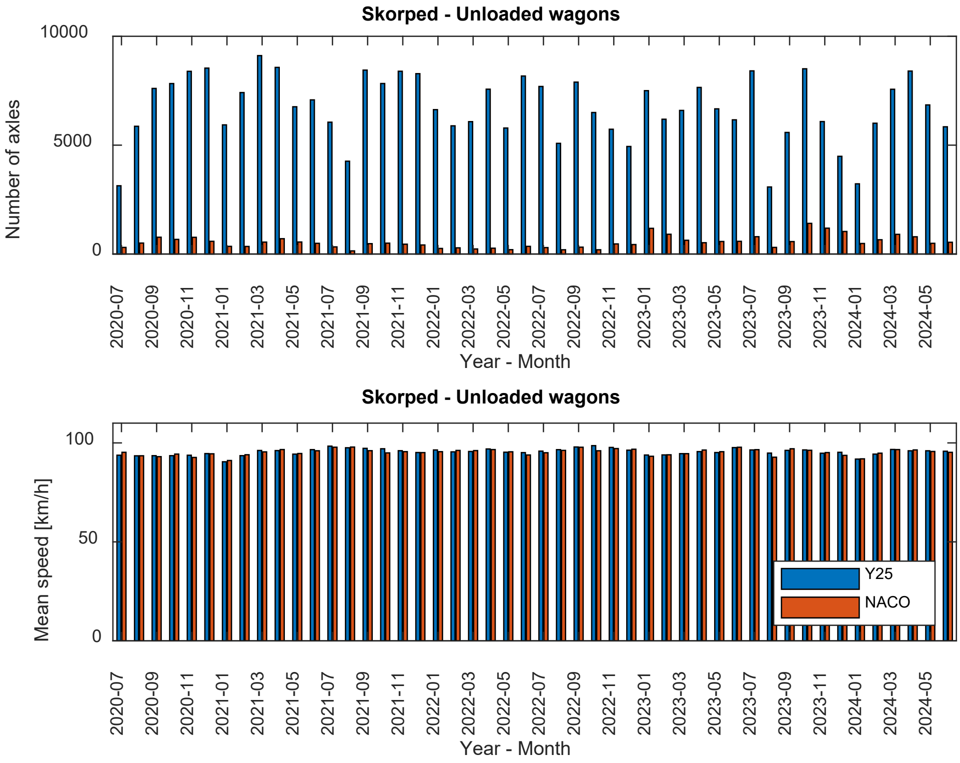
(d)

Figure 6.2 Long-term measurement in the Schenck detector at Degerbäcken – loaded steel shuttle wagons: (a) Number of measured axles with either Y25 or NACO bogies, and mean vehicle speed. (b) Mean axle load. (c) Mean of dynamic loads per wheel – left side, (d) Mean of dynamic loads per wheel – right side.

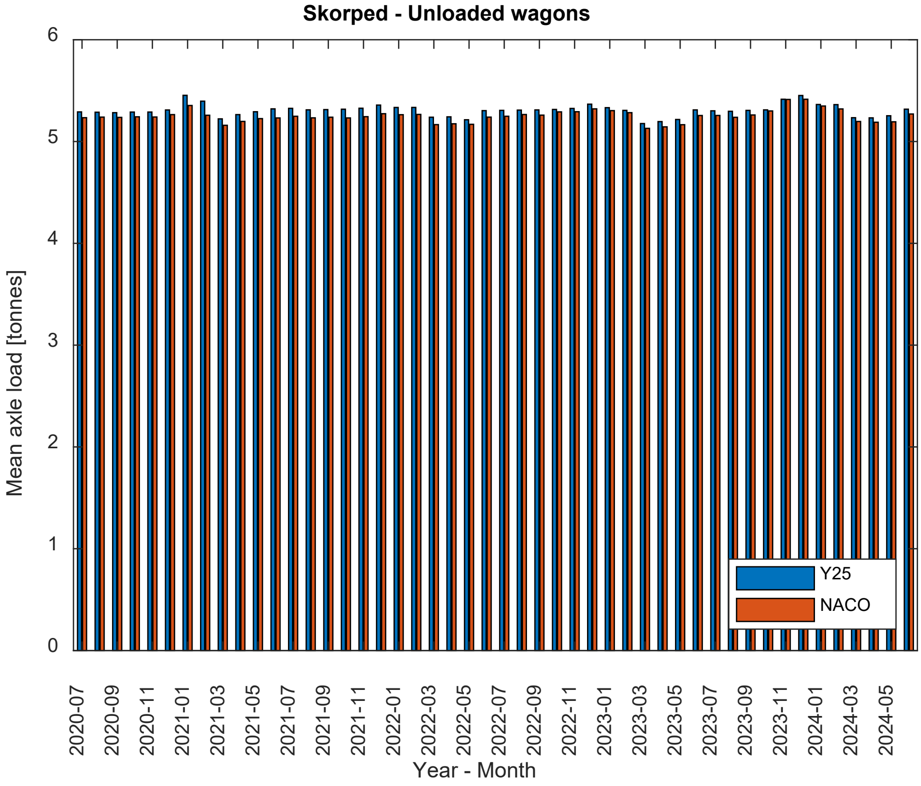
6.5 Case study 2: Long-term assessment of detector at Skorped

For the unloaded steel shuttle wagons, data from the Schenck Wheelscan2 detector at Skorped has been extracted from July 2020 to June 2024, se Figure 6.3. The corresponding data for the loaded steel shuttle wagons are shown in Figure 6.4.

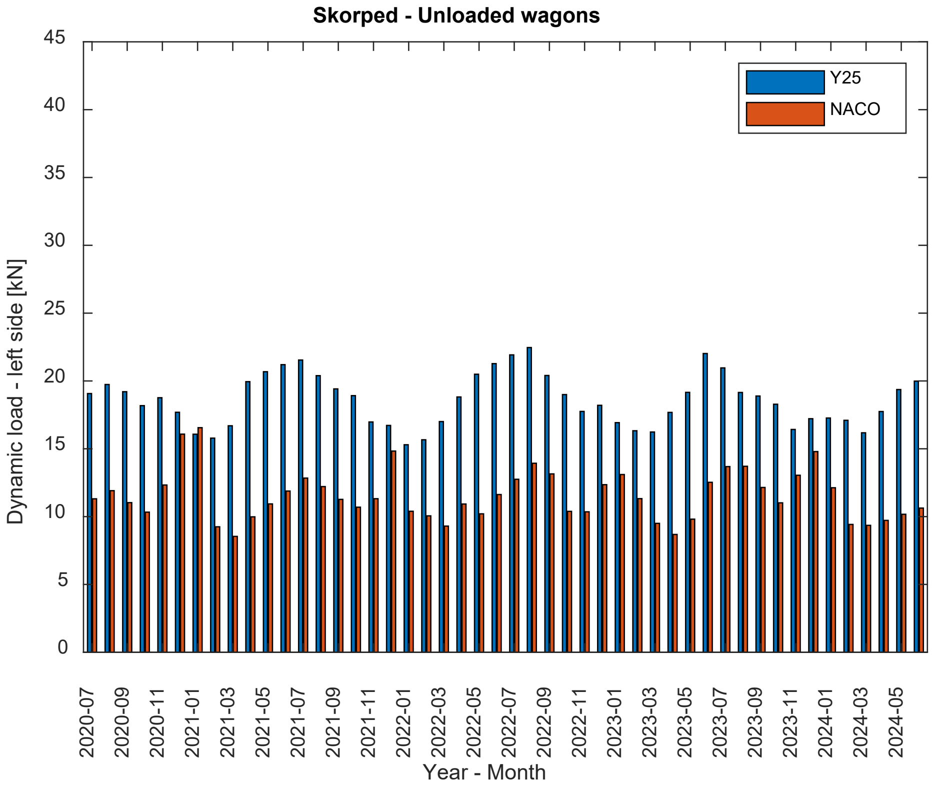
- The mean vehicle speed (evaluated over the period July 2020 – June 2024) of the unloaded and loaded Y25 wagons is 95.5 km/h and 79.9 km/h, respectively, see Figures 6.3(a) and 6.4(a).
- The mean axle load of the unloaded and loaded Y25 wagons is 5.3 tonnes and 21.3 tonnes, respectively, see Figures 6.3(b) and 6.4(b). The corresponding axle loads for the NACO wagons are very similar. These axle loads are similar to those measured at Degerbäcken.
- The WILD at Skorped seems to be consistent and accurate in terms of measured axle loads for the unloaded wagons. There seems to be a small increase in axle loads each winter, which is similar to the trend recorded at Degerbäcken.
- The Y25 bogies generate higher dynamic wheel loads than the NACO bogies due to the difference in braking systems, see Figures 6.3(c,d) and 6.4(c,d). The mean dynamic loads for the loaded Y25 and NACO bogies (evaluated over the period July 2020 – June 2024) are 16.4 kN and 10.7 kN, respectively. These mean values are similar to those measured at Degerbäcken.
- In terms of dynamic loads measured for the unloaded Y25 bogies, there is a remarkable recurrent trend that loads are higher in the summer, which is opposite to what has been measured at Degerbäcken where dynamic loads were higher in the winter. A similar seasonal variation is seen for the NACO bogies. However, for the NACO bogies there is in addition also an increase in dynamic loads in the winter, see Figures 6.3(c,d) and 6.4(c,d).
- Based on the evaluated mean value per month, the dynamic loads measured on the left and right sides are similar in magnitude.
- The dynamic loads generated by the loaded wagons are smaller than the corresponding loads generated by the unloaded wagons, cf. Figures 6.3(c,d) and 6.4(c,d). This is opposite to the trend recorded at Degerbäcken. The seasonal variation is not as evident as for the unloaded wagons.
- Overall, the WILD at Skorped seems to measure correct mean loads both in unloaded and loaded vehicle conditions. According to Figures 4.12 and 4.13, irregularities in track geometry and track stiffness are present in the detector area. The variation in support conditions along the detector could have an influence on the vehicle dynamics and the accuracy of the detector.


Skorped - Unloaded wagons
10000
5000
0
Number of axles
2020-07
2020-09
2020-11
2021-01
2021-03
2021-05
2021-07
2021-09
2021-11
2022-01
2022-03
2022-05
2022-07
2022-09
2022-11
2023-01
2023-03
2023-05
2023-07
2023-09
2023-11
2024-01
2024-03
2024-05
Year - Month
Skorped - Unloaded wagons
100
50
0
Mean speed [km/h]
Y25
NACO
2020-07
2020-09
2020-11
2021-01
2021-03
2021-05
2021-07
2021-09
2021-11
2022-01
2022-03
2022-05
2022-07
2022-09
2022-11
2023-01
2023-03
2023-05
2023-07
2023-09
2023-11
2024-01
2024-03
2024-05
Year - Month

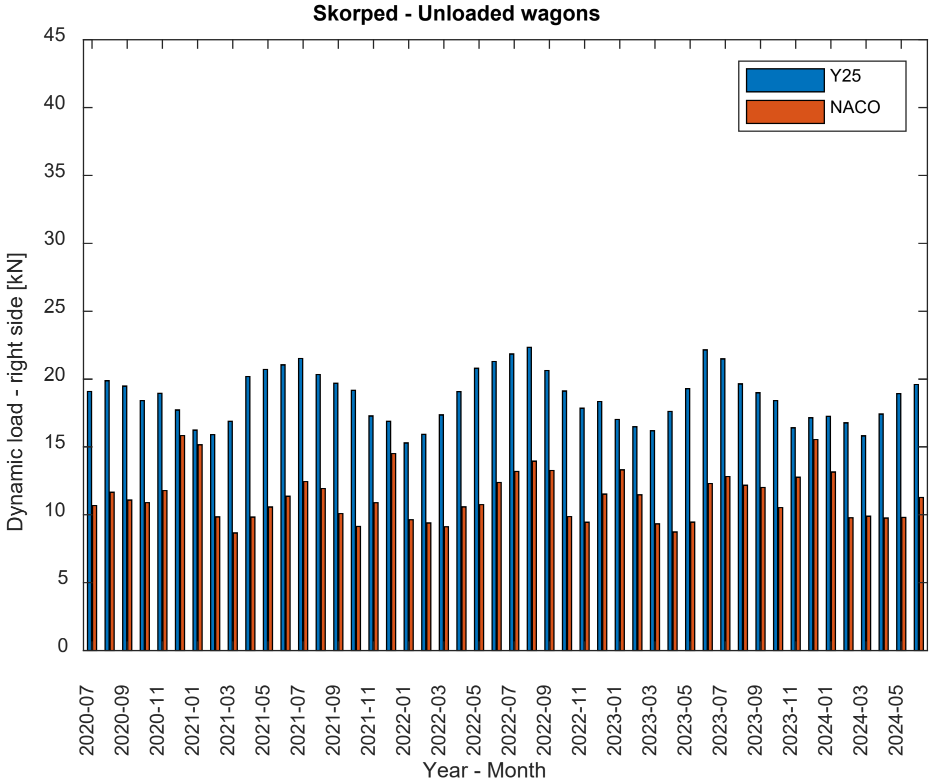
(a)


Skorped - Unloaded wagons
6
5
4
3
2
1
0
Mean axle load [tonnes]
Y25
NACO
2020-07
2020-09
2020-11
2021-01
2021-03
2021-05
2021-07
2021-09
2021-11
2022-01
2022-03
2022-05
2022-07
2022-09
2022-11
2023-01
2023-03
2023-05
2023-07
2023-09
2023-11
2024-01
2024-03
2024-05
Year - Month

(b)

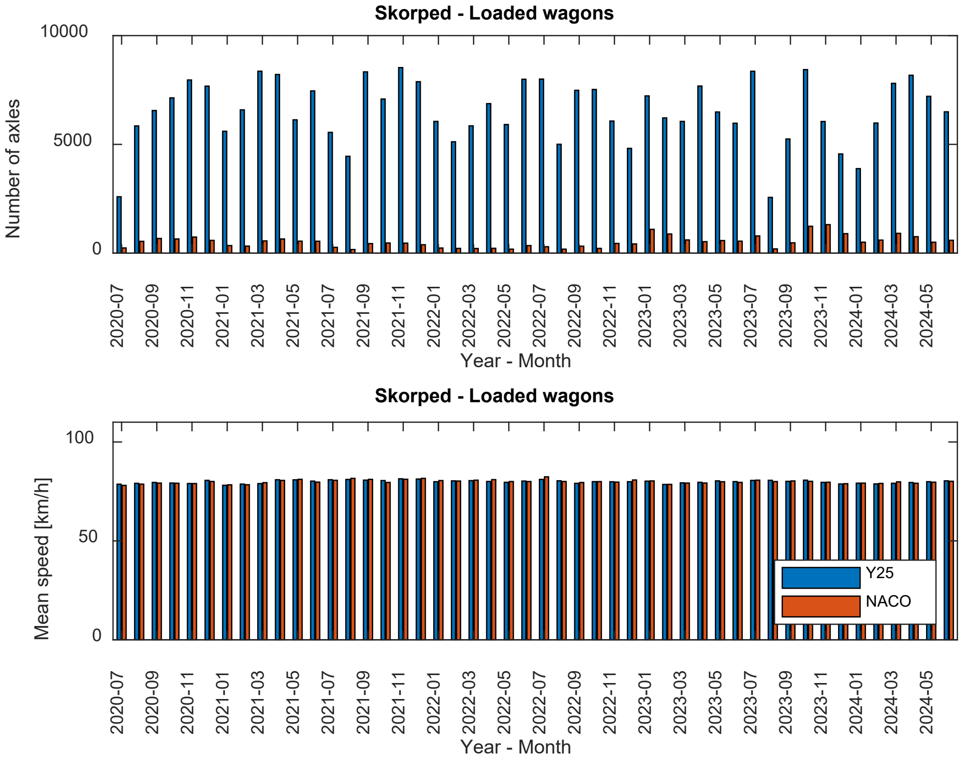


(c)

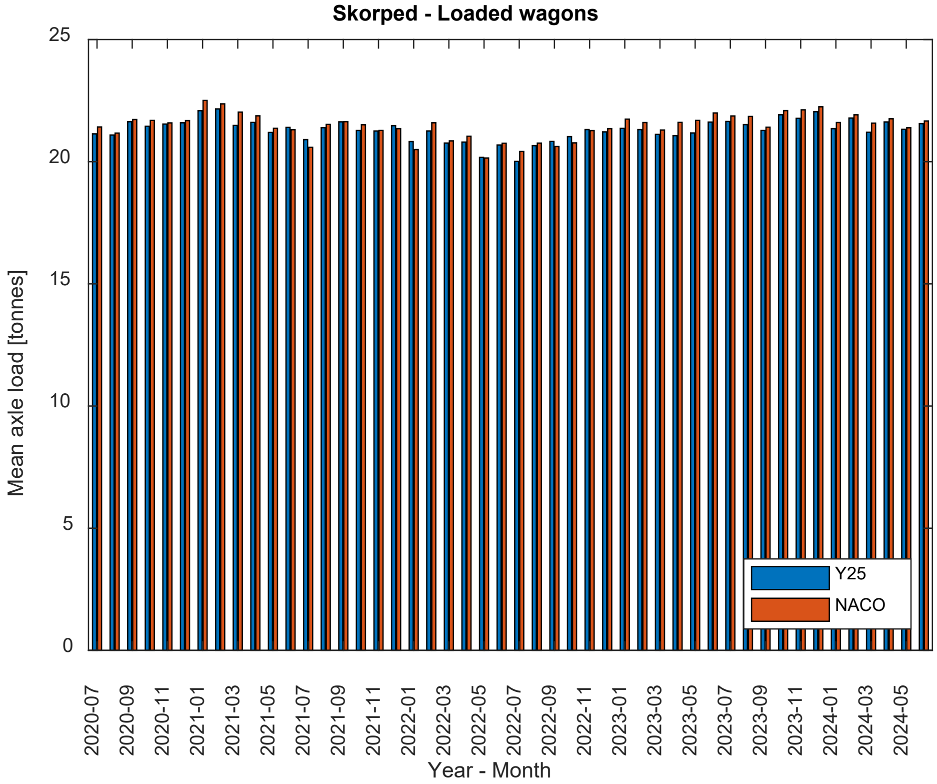


(d)

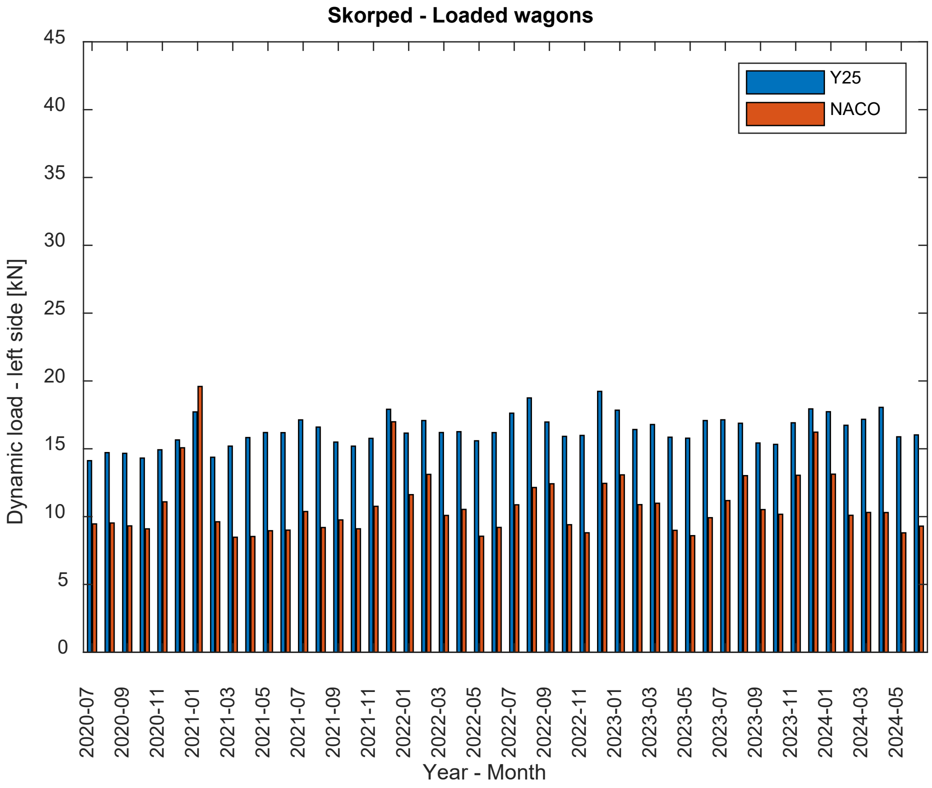
Figure 6.3 Long-term measurement in the Schenck detector at Skorped – unloaded steel shuttle wagons: (a) Number of measured axles with either Y25 or NACO bogies, and mean vehicle speed. (b) Mean axle load. (c) Mean of dynamic loads per wheel – left side, (d) Mean of dynamic loads per wheel – right side.


Skorped - Loaded wagons
Number of axles
10000
5000
0
2020-07
2020-09
2020-11
2021-01
2021-03
2021-05
2021-07
2021-09
2021-11
2022-01
2022-03
2022-05
2022-07
2022-09
2022-11
2023-01
2023-03
2023-05
2023-07
2023-09
2023-11
2024-01
2024-03
2024-05
Year - Month
Skorped - Loaded wagons
Mean speed [km/h]
100
50
0
Y25
NACO
2020-07
2020-09
2020-11
2021-01
2021-03
2021-05
2021-07
2021-09
2021-11
2022-01
2022-03
2022-05
2022-07
2022-09
2022-11
2023-01
2023-03
2023-05
2023-07
2023-09
2023-11
2024-01
2024-03
2024-05
Year - Month

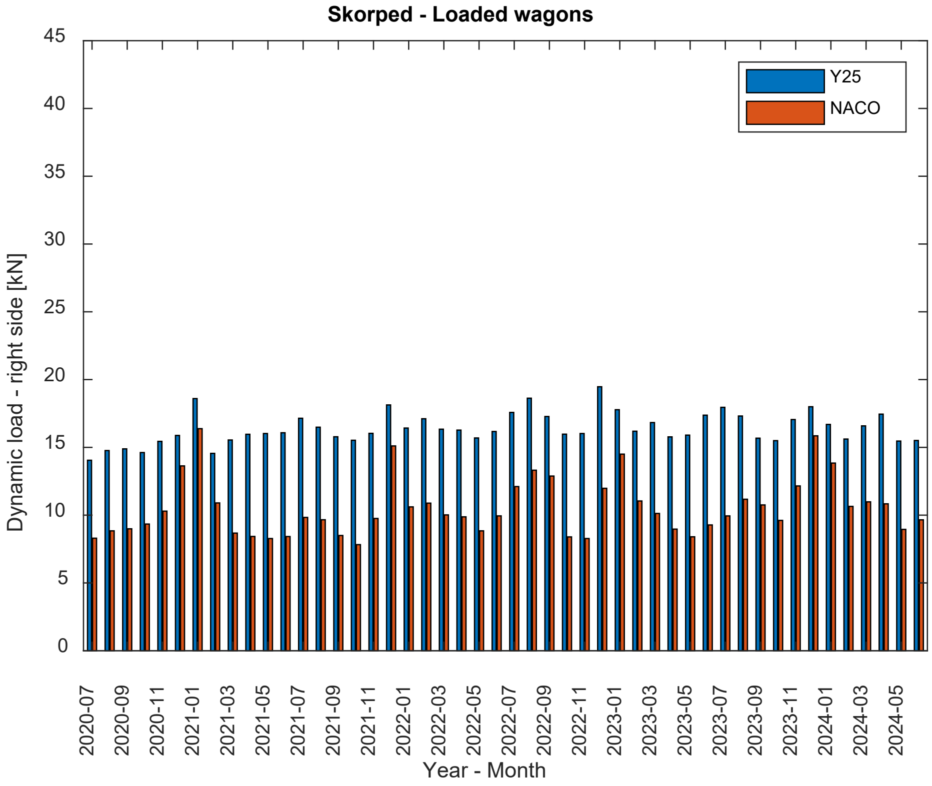
(a)


Skorped - Loaded wagons
Mean axle load [tonnes]
25
20
15
10
5
0
Y25
NACO
2020-07
2020-09
2020-11
2021-01
2021-03
2021-05
2021-07
2021-09
2021-11
2022-01
2022-03
2022-05
2022-07
2022-09
2022-11
2023-01
2023-03
2023-05
2023-07
2023-09
2023-11
2024-01
2024-03
2024-05
Year - Month

(b)



(c)



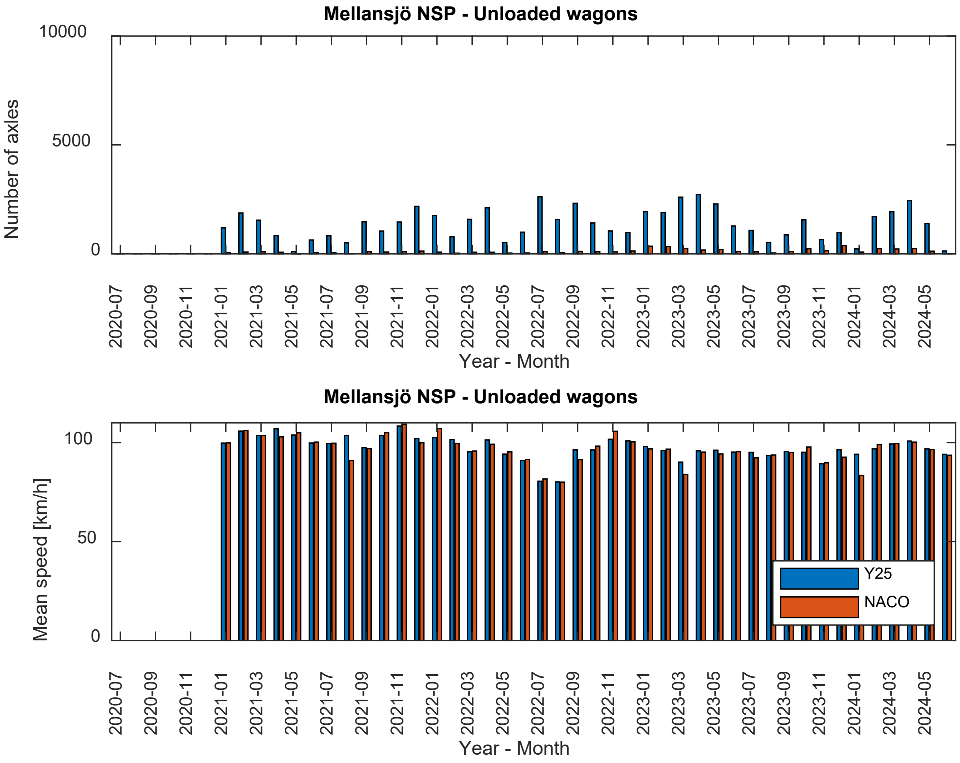
(d)

Figure 6.4 Long-term measurement in the Schenck detector at Skorped – loaded steel shuttle wagons: (a) Number of measured axles with either Y25 or NACO bogies, and mean vehicle speed. (b) Mean axle load. (c) Mean of dynamic loads per wheel – left side, (d) Mean of dynamic loads per wheel – right side.

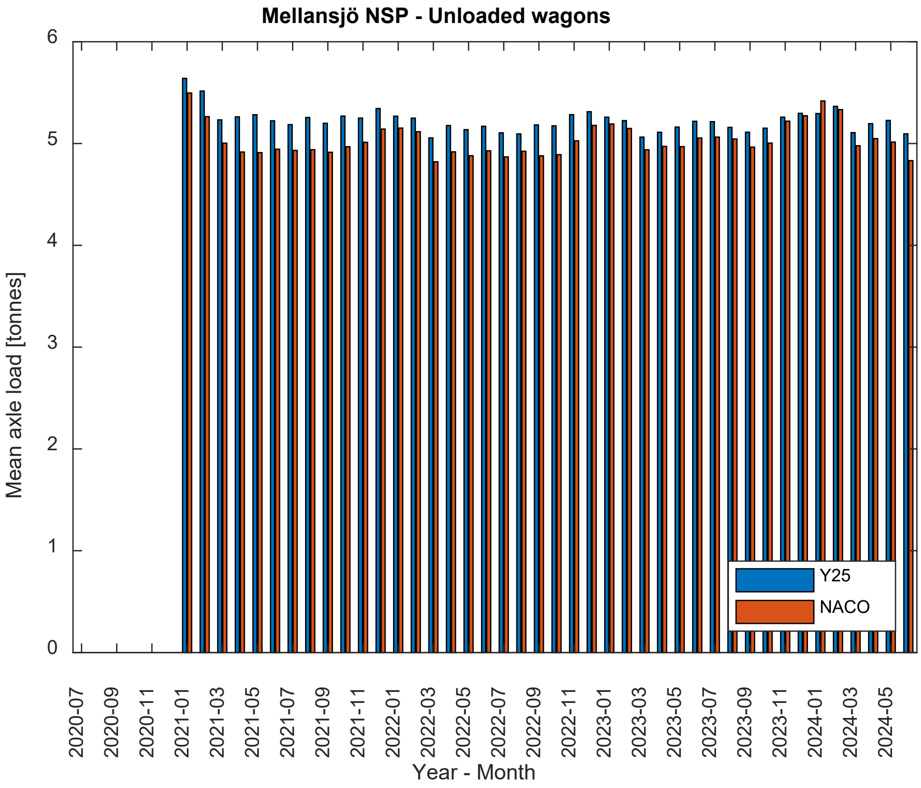
6.6 Case study 2: Long-term assessment of detector at Mellansjö NSP

For the unloaded steel shuttle wagons, data from the PHOENIX MDS detector at Mellansjö NSP has been extracted from January 2021 to June 2024, se Figure 6.5. The corresponding data for the loaded steel shuttle wagons are shown in Figure 6.6.

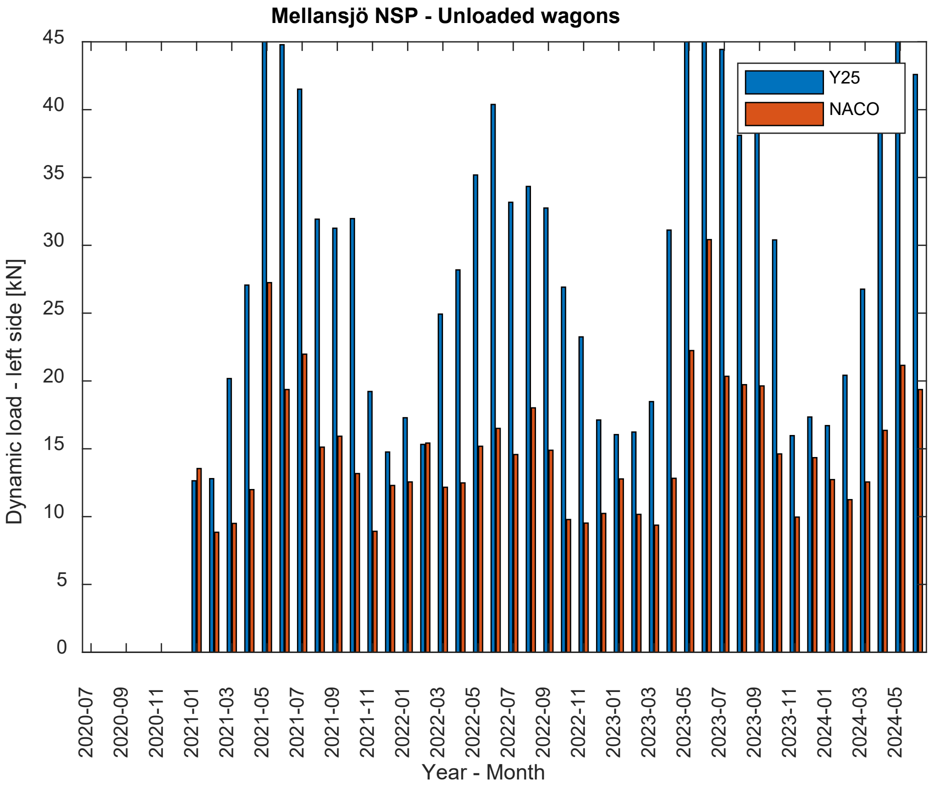
- The number of steel shuttle wagons passing the detector at Mellansjö NSP is much lower than for the detectors at Degerbäcken and Skorped. In particular, the loaded wagons are very few (besides July 2022). Due to traffic control reasons, the USP at Mellansjö is used also for the south-bound trains. This means that outliers in terms of severe wheel tread damage could potentially have some influence on the evaluated mean values.
- The mean vehicle speed (evaluated over the period January 2021 – June 2024) of the unloaded and loaded Y25 wagons is 97.5 km/h and 74.0 km/h, respectively, see Figures 6.5(a) and 6.6(a).
- The mean axle load of the unloaded and Y25 loaded wagons is 5.2 tonnes and 22.0 tonnes, respectively, see Figures 6.5(b) and 6.6(b). The corresponding axle loads for the NACO wagons are 5.0 tonnes and 21.8 tonnes.
- The WILD at Mellansjö NSP seems to be consistent and accurate in terms of measured axle loads for the unloaded wagons. There seems to be a small increase in axle loads each winter that could be due to added weight from snow and ice.
- The Y25 bogies generate higher dynamic wheel loads than the NACO bogies due to the difference in braking systems, see Figures 6.5(c,d) and 6.6(c,d). This is in line with the measured data from the Schenck detectors.
- In terms of dynamic loads measured for the unloaded Y25 bogies, there is a remarkable and unexpected trend that loads are higher in the summer. The dynamic loads are higher than the mean load per wheel, indicating recurrent momentaneous losses of wheel–rail contact. If this is correct, repeated impact noise should be hearable from the detector, at least from the Y25 bogies. A similar seasonal variation is seen for the NACO bogies. Thus, the seasonal variation is independent of braking system and bogie type. **The reason for this is unknown.**
- Based on the evaluated mean value per month for the unloaded wagons, the dynamic loads measured on the left and right sides are similar in magnitude.


Mellansjö NSP - Unloaded wagons
Number of axles
10000
5000
0
2020-07
2020-09
2020-11
2021-01
2021-03
2021-05
2021-07
2021-09
2021-11
2022-01
2022-03
2022-05
2022-07
2022-09
2022-11
2023-01
2023-03
2023-05
2023-07
2023-09
2023-11
2024-01
2024-03
2024-05
Year - Month
Mellansjö NSP - Unloaded wagons
Mean speed [km/h]
100
50
0
Y25
NACO
Year - Month

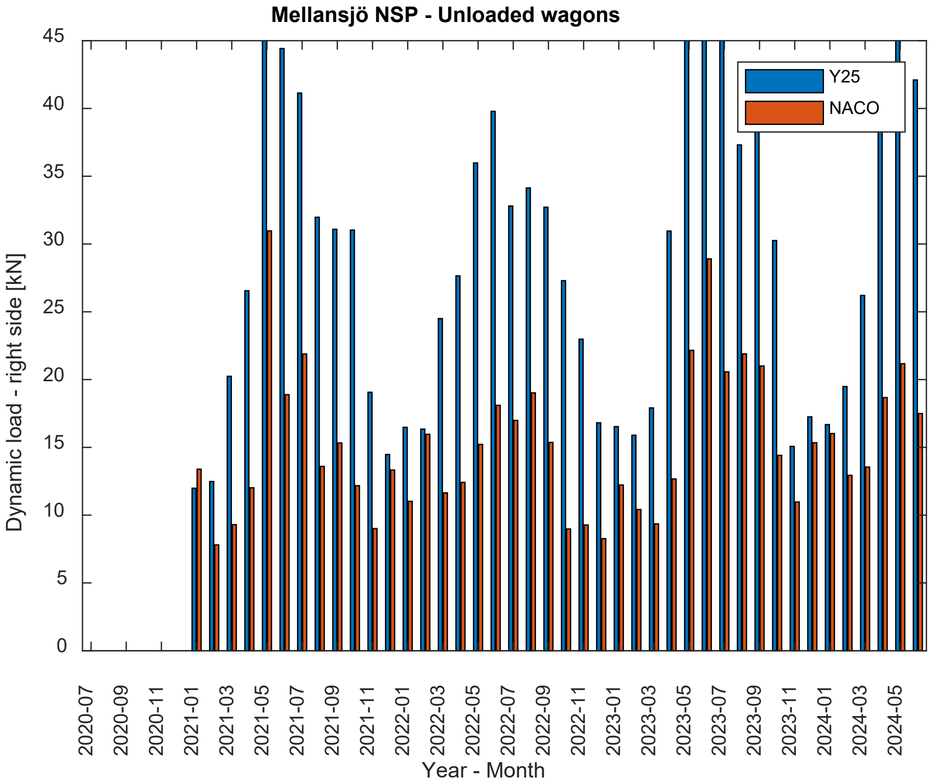
(a)


Mellansjö NSP - Unloaded wagons
Mean axle load [tonnes]
6
5
4
3
2
1
0
Y25
NACO
2020-07
2020-09
2020-11
2021-01
2021-03
2021-05
2021-07
2021-09
2021-11
2022-01
2022-03
2022-05
2022-07
2022-09
2022-11
2023-01
2023-03
2023-05
2023-07
2023-09
2023-11
2024-01
2024-03
2024-05
Year - Month

(b)

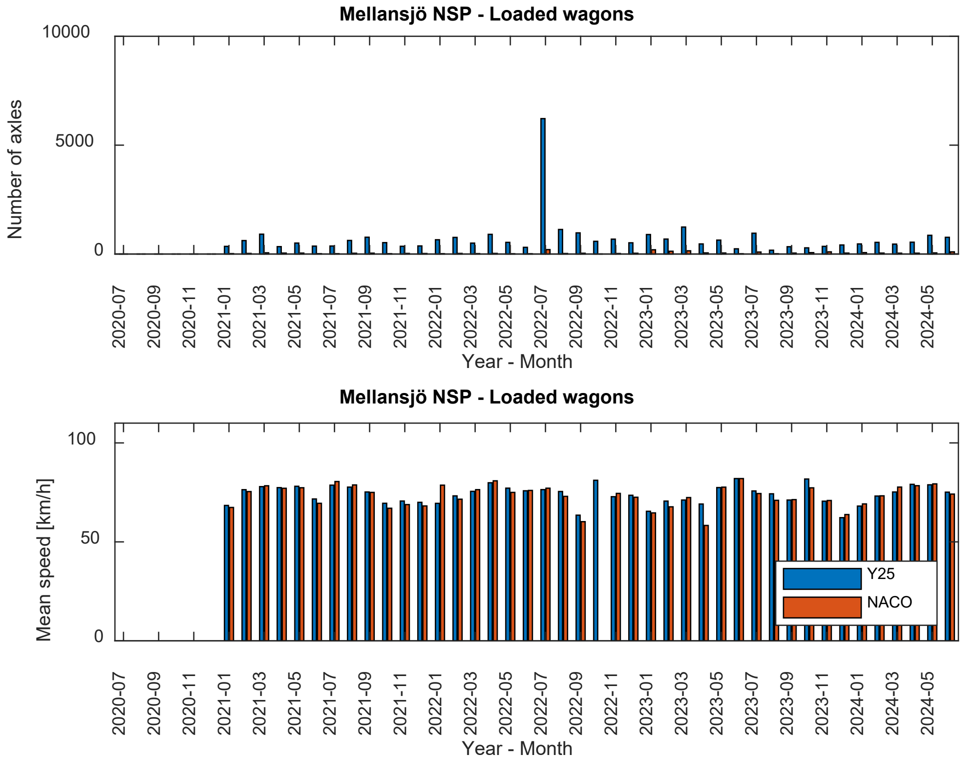


(c)

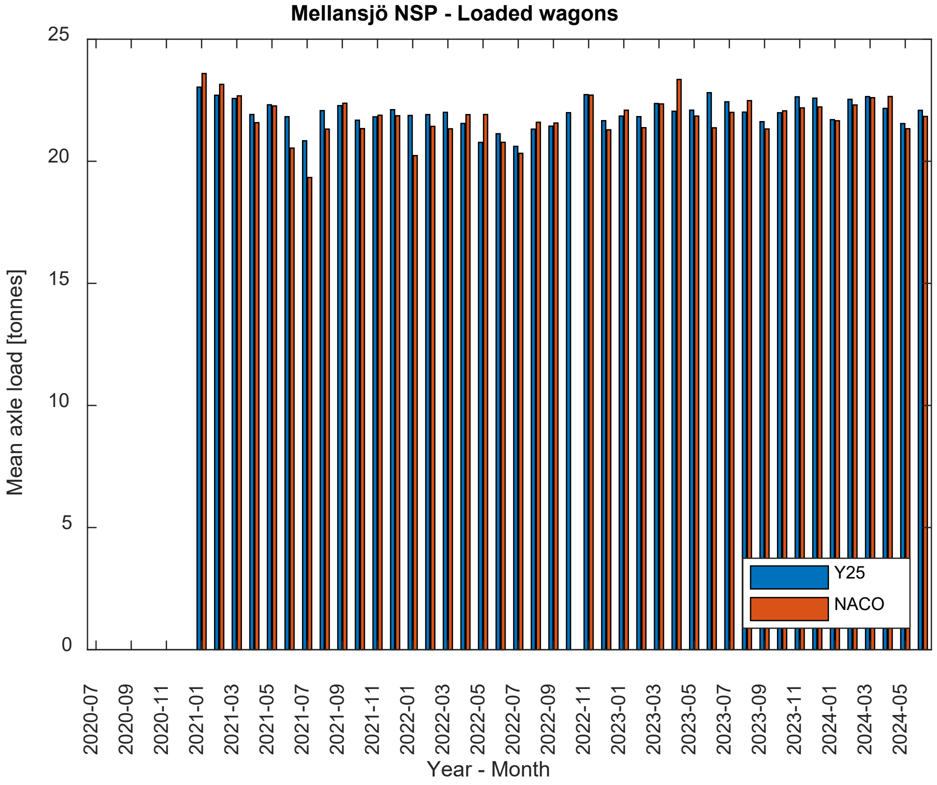


(d)

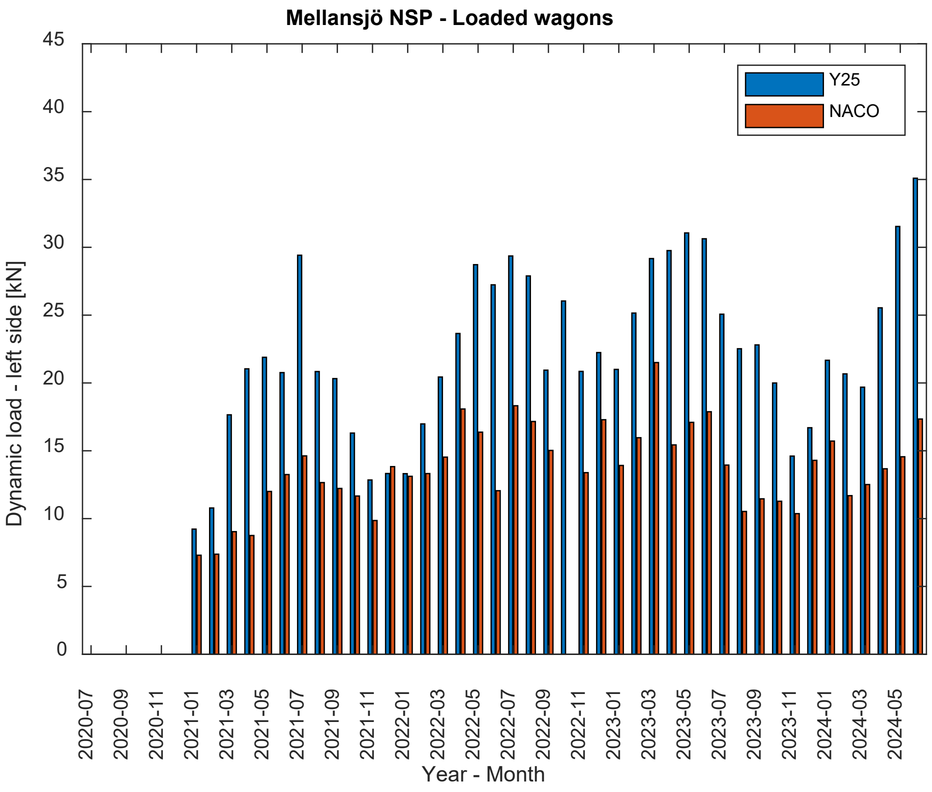
Figure 6.5 Long-term measurement in the PHOENIX MDS detector at Mellansjö NSP – unloaded steel shuttle wagons: (a) Number of measured axles with either Y25 or NACO bogies, and mean vehicle speed. (b) Mean axle load. (c) Mean of dynamic loads per wheel – left side, (d) Mean of dynamic loads per wheel – right side.


Mellansjö NSP - Loaded wagons
Number of axles
10000
5000
0
2020-07
2020-09
2020-11
2021-01
2021-03
2021-05
2021-07
2021-09
2021-11
2022-01
2022-03
2022-05
2022-07
2022-09
2022-11
2023-01
2023-03
2023-05
2023-07
2023-09
2023-11
2024-01
2024-03
2024-05
Year - Month
Mellansjö NSP - Loaded wagons
Mean speed [km/h]
100
50
0
Y25
NACO
Year - Month

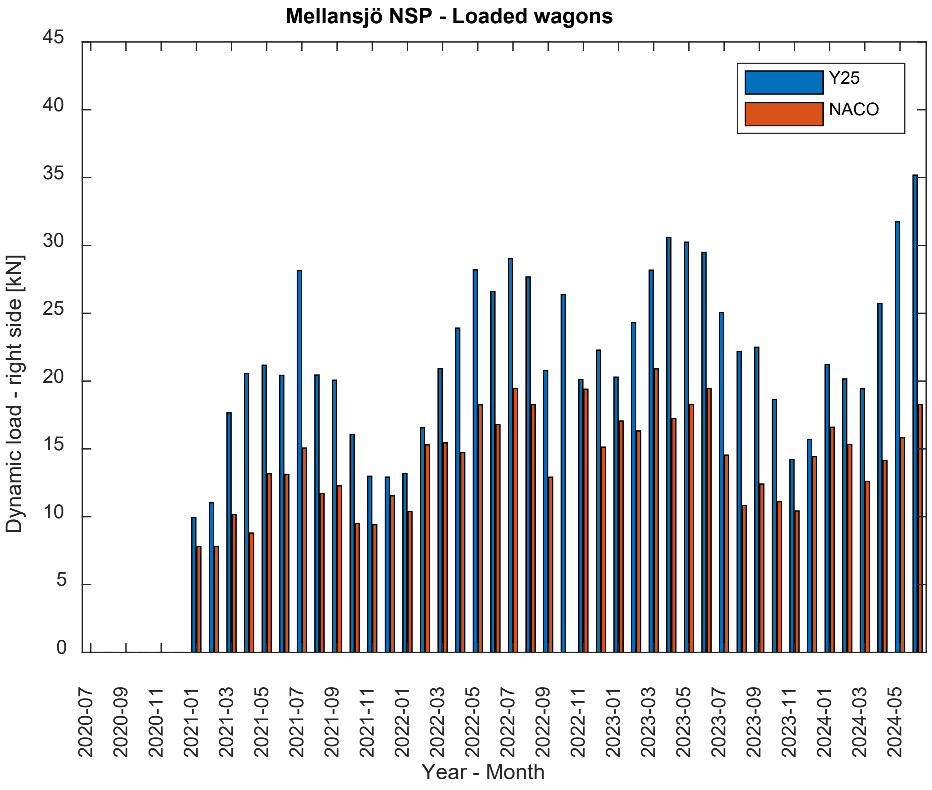
(a)


Mellansjö NSP - Loaded wagons
Mean axle load [tonnes]
25
20
15
10
5
0
Y25
NACO
2020-07
2020-09
2020-11
2021-01
2021-03
2021-05
2021-07
2021-09
2021-11
2022-01
2022-03
2022-05
2022-07
2022-09
2022-11
2023-01
2023-03
2023-05
2023-07
2023-09
2023-11
2024-01
2024-03
2024-05
Year - Month

(b)



(c)



(d)

Figure 6.6 Long-term measurement in the PHOENIX MDS detector at Mellansjö NSP – loaded steel shuttle wagons: (a) Number of measured axles with either Y25 or NACO bogies, and mean vehicle speed. (b) Mean axle load. (c) Mean of dynamic loads per wheel – left side, (d) Mean of dynamic loads per wheel – right side.

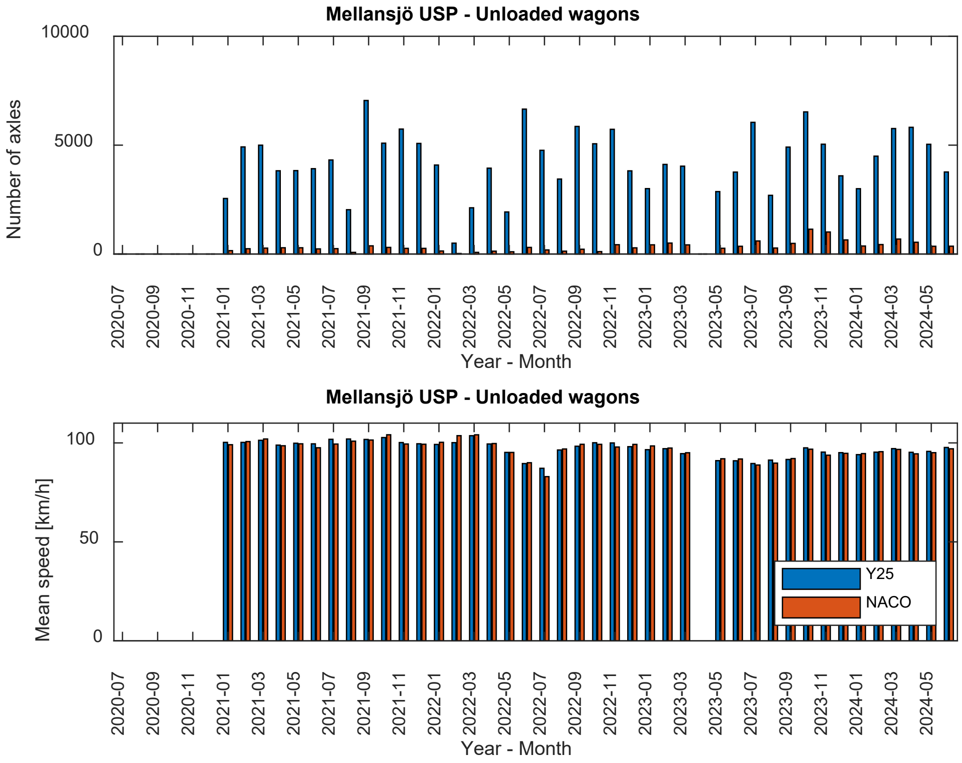
6.7 Case study 2: Long-term assessment of detector at Mellansjö USP

For the unloaded steel shuttle wagons, data from the PHOENIX MDS detector at Mellansjö USP has been extracted from January 2021 to June 2024, se Figure 6.7. The corresponding data for the loaded steel shuttle wagons are shown in Figure 6.8.

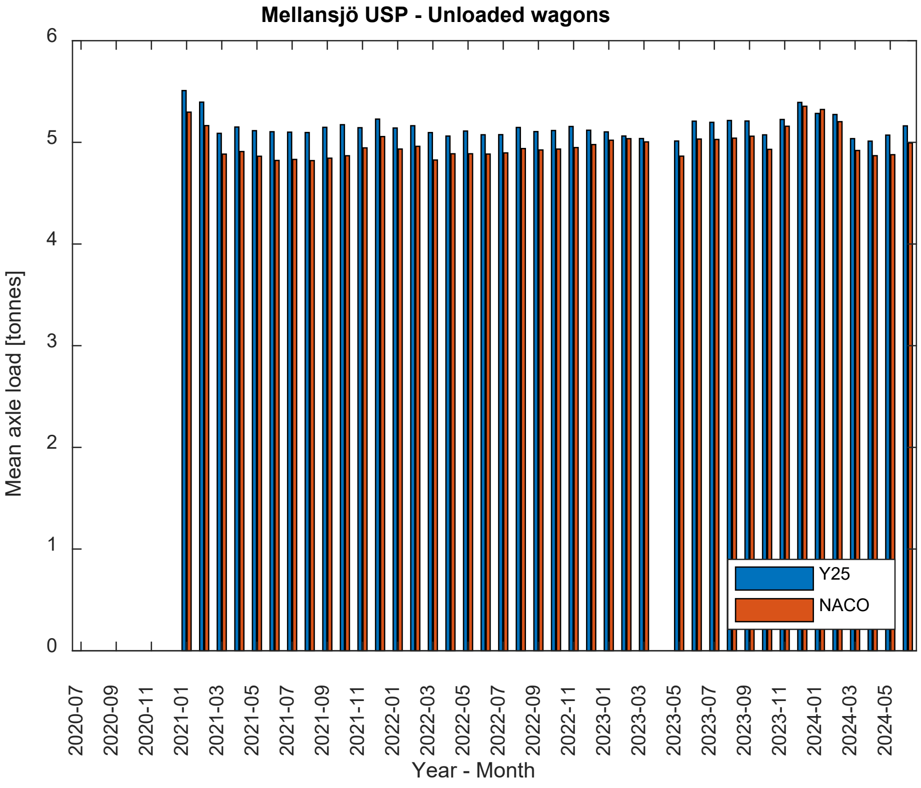
- The mean vehicle speed (evaluated over the period January 2021 – June 2024) of the unloaded and loaded Y25 wagons is 97.1 km/h and 74.0 km/h, respectively, see Figures 6.7(a) and 6.8(a).
- The mean axle load of the unloaded and loaded Y25 wagons is 5.2 tonnes and 22.0 tonnes, respectively, see Figures 6.7(b) and 6.8(b). The corresponding axle loads for the NACO wagons are similar. These axle loads are similar to those measured at Degerbäcken.
- The WILD at Mellansjö USP seems to be consistent and accurate in terms of measured axle loads for the unloaded wagons.
- The Y25 bogies generate higher dynamic wheel loads than the NACO bogies due to the difference in braking systems, see Figures 6.7(c,d) and 6.8(c,d).
- The measured dynamic loads are significantly higher for the unloaded wagons, cf. Figures 6.7(c,d) and 6.8(c,d). The dynamic loads are higher than the mean load per wheel, indicating recurrent momentaneous losses of wheel–rail contact. If this is correct, repeated impact noise should be hearable from the detector, at least from the Y25 bogies.
- For both unloaded and loaded wagons, there is a remarkable and unexpected trend that dynamic loads are higher in the summer. The same trend is observed for the NACO bogies.
- For both unloaded and loaded wagons, similar dynamic loads are measured on the left and right sides of the detector.[5]
- Overall, the trend with higher dynamic loads measured in the summers (independent of bogie type) and the substantially higher dynamic loads recorded for the unloaded wagons indicate that the accuracy of the WILD needs to be verified.

---

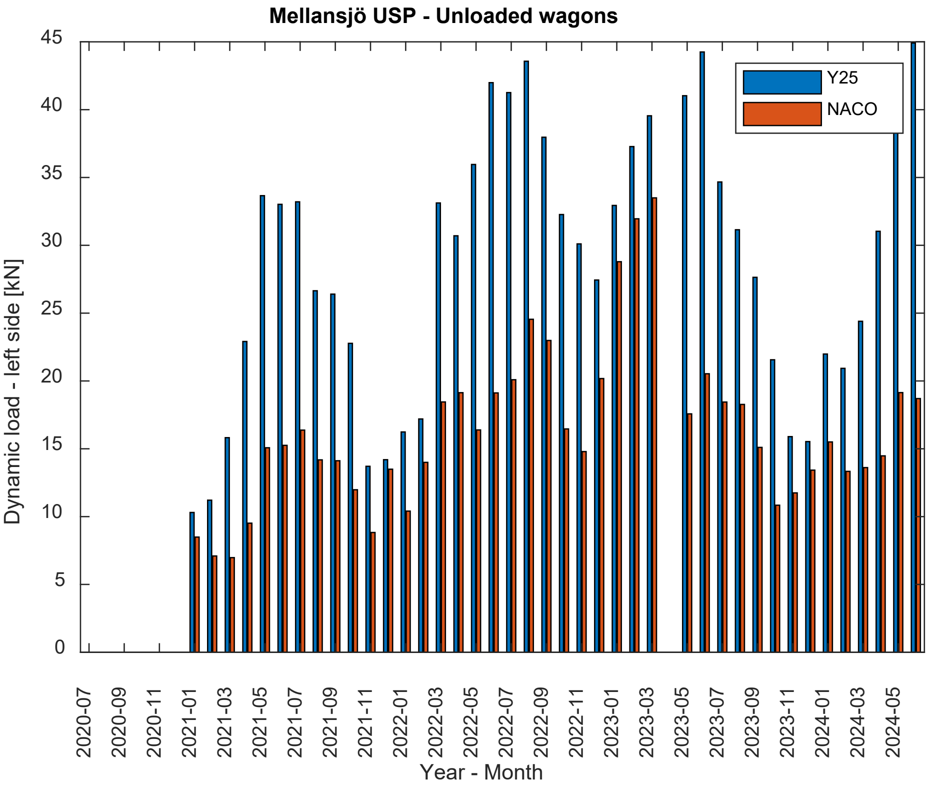
[5] Left and right refer to the sides of the wagon. Viewed from above, there is an A-end where the axle numbering starts, and a left and right side. The other end is the B-end. Data from detectors always indicate measurements relative to the wagon for tagged vehicles, not the track. (The wagons can be oriented in two ways in the train.)


Mellansjö USP - Unloaded wagons
Number of axles
10000
5000
0
2020-07
2020-09
2020-11
2021-01
2021-03
2021-05
2021-07
2021-09
2021-11
2022-01
2022-03
2022-05
2022-07
2022-09
2022-11
2023-01
2023-03
2023-05
2023-07
2023-09
2023-11
2024-01
2024-03
2024-05
Year - Month
Mellansjö USP - Unloaded wagons
Mean speed [km/h]
100
50
0
Y25
NACO
Year - Month

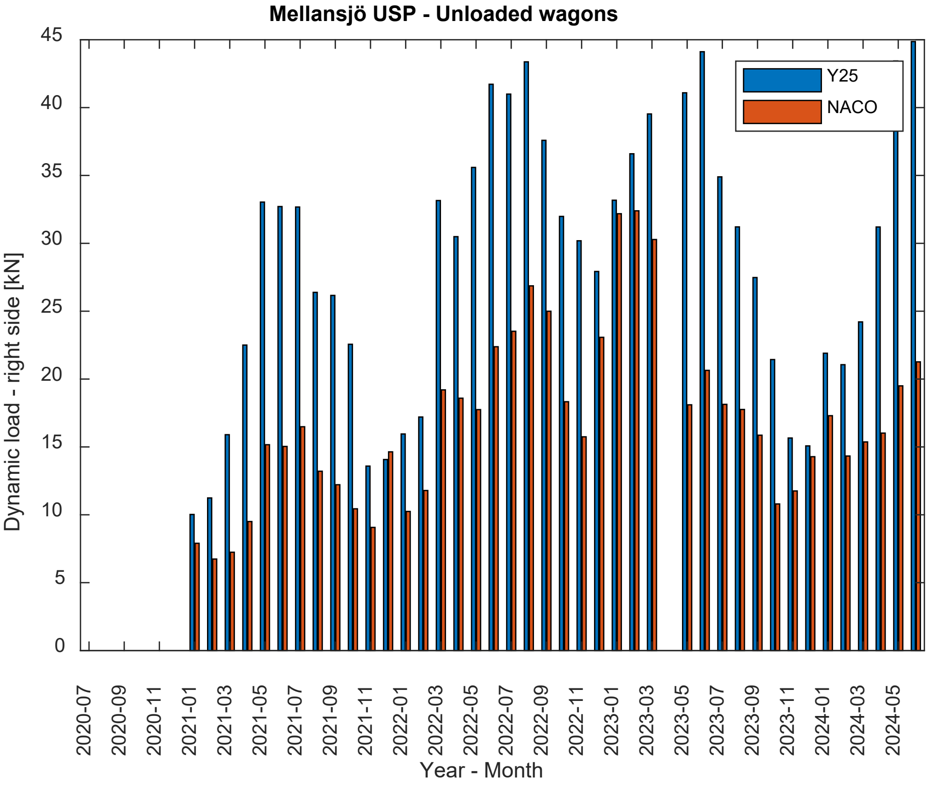
(a)


Mellansjö USP - Unloaded wagons
Mean axle load [tonnes]
6
5
4
3
2
1
0
Y25
NACO
2020-07
2020-09
2020-11
2021-01
2021-03
2021-05
2021-07
2021-09
2021-11
2022-01
2022-03
2022-05
2022-07
2022-09
2022-11
2023-01
2023-03
2023-05
2023-07
2023-09
2023-11
2024-01
2024-03
2024-05
Year - Month

(b)

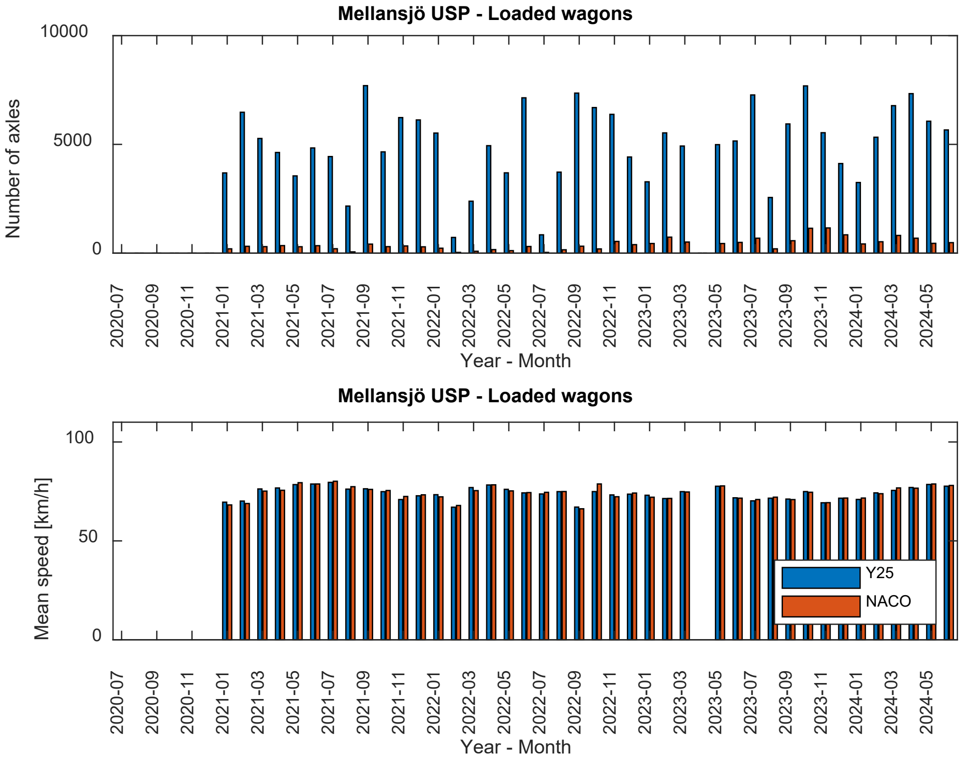


(c)

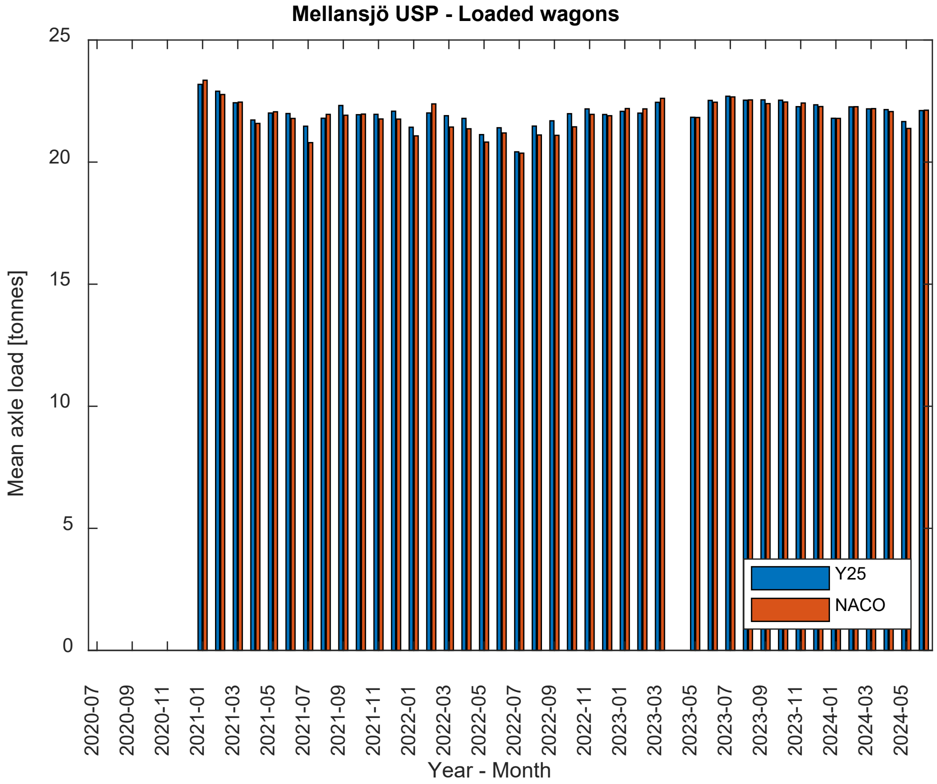


(d)

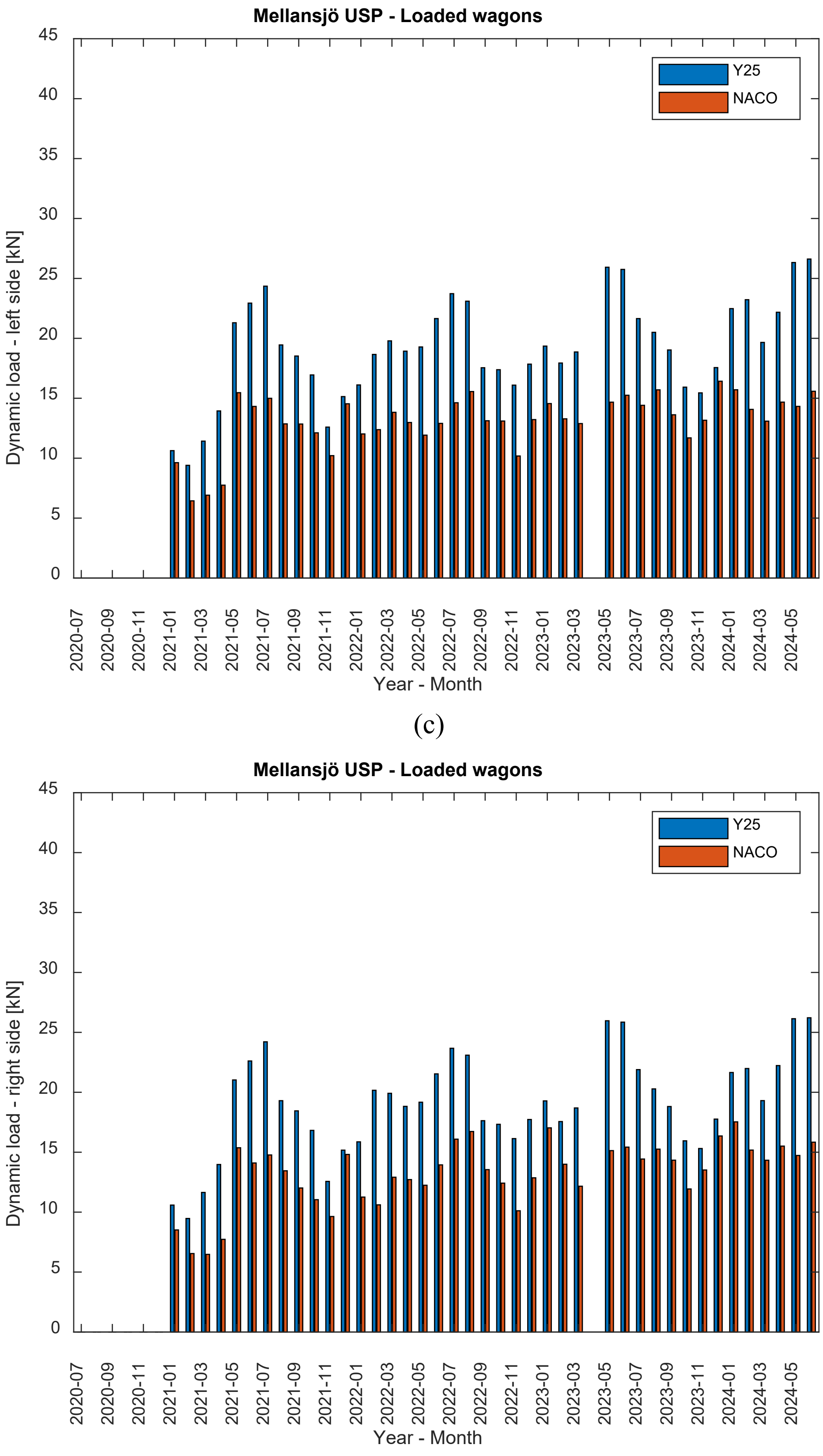
Figure 6.7 Long-term measurement in the PHOENIX MDS detector at Mellansjö USP – unloaded steel shuttle wagons: (a) Number of measured axles with either Y25 or NACO bogies, and mean vehicle speed. (b) Mean axle load. (c) Mean of dynamic loads per wheel – left side, (d) Mean of dynamic loads per wheel – right side.


Mellansjö USP - Loaded wagons
Number of axles
10000
5000
0
2020-07
2020-09
2020-11
2021-01
2021-03
2021-05
2021-07
2021-09
2021-11
2022-01
2022-03
2022-05
2022-07
2022-09
2022-11
2023-01
2023-03
2023-05
2023-07
2023-09
2023-11
2024-01
2024-03
2024-05
Year - Month
Mellansjö USP - Loaded wagons
Mean speed [km/h]
100
50
0
Y25
NACO
Year - Month

(a)


Mellansjö USP - Loaded wagons
Mean axle load [tonnes]
25
20
15
10
5
0
Y25
NACO
2020-07
2020-09
2020-11
2021-01
2021-03
2021-05
2021-07
2021-09
2021-11
2022-01
2022-03
2022-05
2022-07
2022-09
2022-11
2023-01
2023-03
2023-05
2023-07
2023-09
2023-11
2024-01
2024-03
2024-05
Year - Month

(b)



(d)

Figure 6.8 Long-term measurement in the PHOENIX MDS detector at Mellansjö USP – loaded steel shuttle wagons: (a) Number of measured axles with either Y25 or NACO bogies, and mean vehicle speed. (b) Mean axle load. (c) Mean of dynamic loads per wheel – left side, (d) Mean of dynamic loads per wheel – right side.

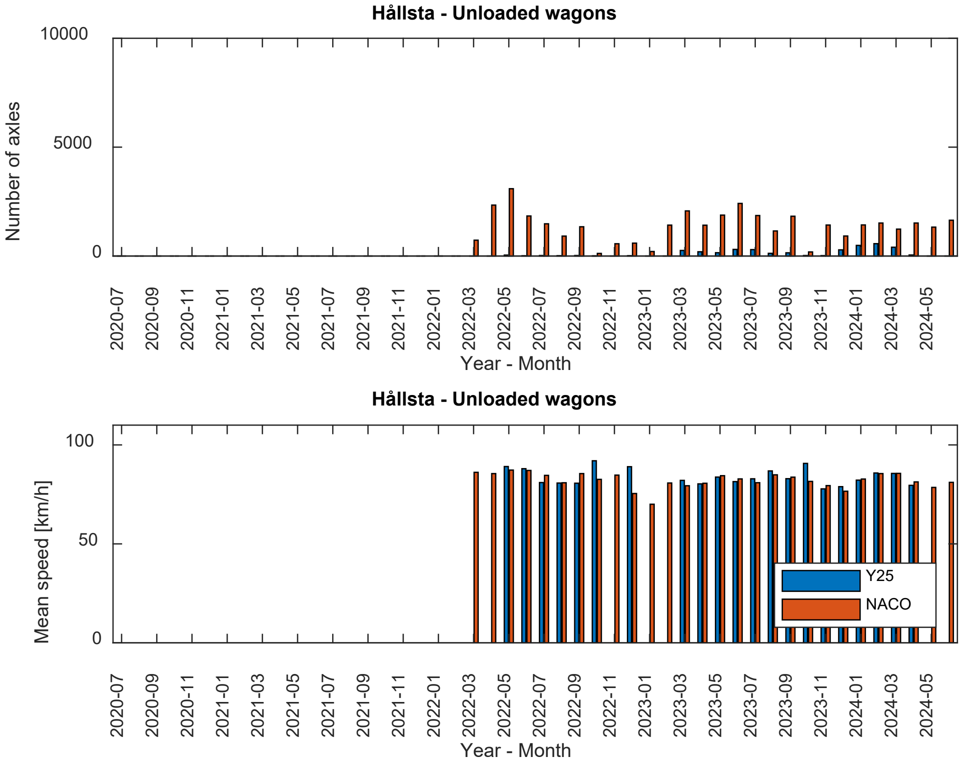
6.8 Case study 2: Long-term assessment of detector at Hållsta

For the unloaded steel shuttle wagons, data from the PHOENIX MDS detector at Hållsta has been extracted from March 2022 to June 2024, se Figure 6.9. The corresponding data for the loaded steel shuttle wagons are shown in Figure 6.10.

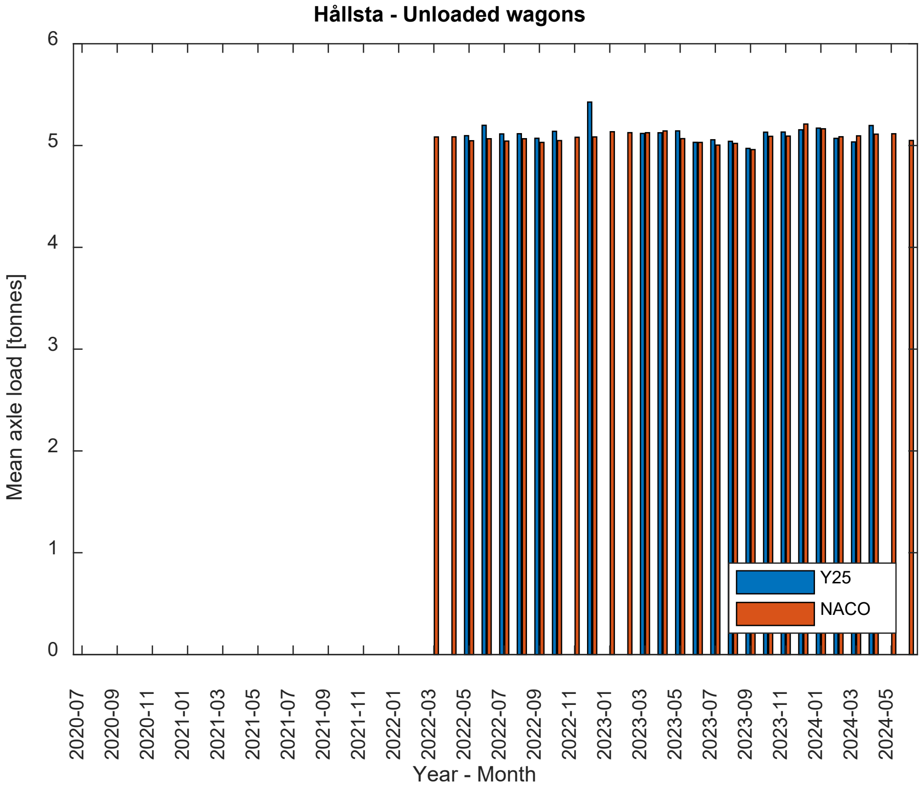
- The number of steel shuttle wagons passing the detector at Hållsta is much lower than for the other detectors studied in this report. Unlike at the other detectors, the NACO bogie is more common than the Y25 bogie.[6]
- The mean vehicle speed (evaluated over the period March 2022 – June 2024) of the unloaded and loaded Y25 wagons is 83.9 km/h and 88.2 km/h, respectively, see Figures 6.9(a) and 6.10(a). Thus, on average at Hållsta, the speed of the loaded steel shuttle trains is higher than the speed of the unloaded shuttle trains.
- The mean axle load of the unloaded and loaded Y25 wagons is 5.1 tonnes and 20.2 tonnes, respectively, see Figures 6.7(b) and 6.8(b). The corresponding axle loads for the NACO wagons are similar. Thus, the axle loads of the loaded wagons are 1 – 2 tonnes lower than those recorded at the other WILDs.
- The Y25 bogies generate higher dynamic wheel loads than the NACO bogies due to the difference in braking systems, see Figures 6.9(c,d) and 6.10(c,d).
- For the Y25 bogies on the loaded wagons, the measured dynamic loads on the left side are significantly higher than on the right side, see Figure 6.10(c,d). For the NACO bogies, the dynamic loads are similar on the left and right sides.
- For both the unloaded and loaded Y25 wagons, there seems to be an unexpected trend that measured dynamic loads were higher in the summers of 2022 and 2023 compared to in the winter 2022/2023. For the winter 2023/2024, dynamic loads were higher than the months before and after. However, note that the number of Y25 bogies passing the detector at Hållsta is low. A similar variation in measured dynamic loads for the NACO bogies is not as evident.

---

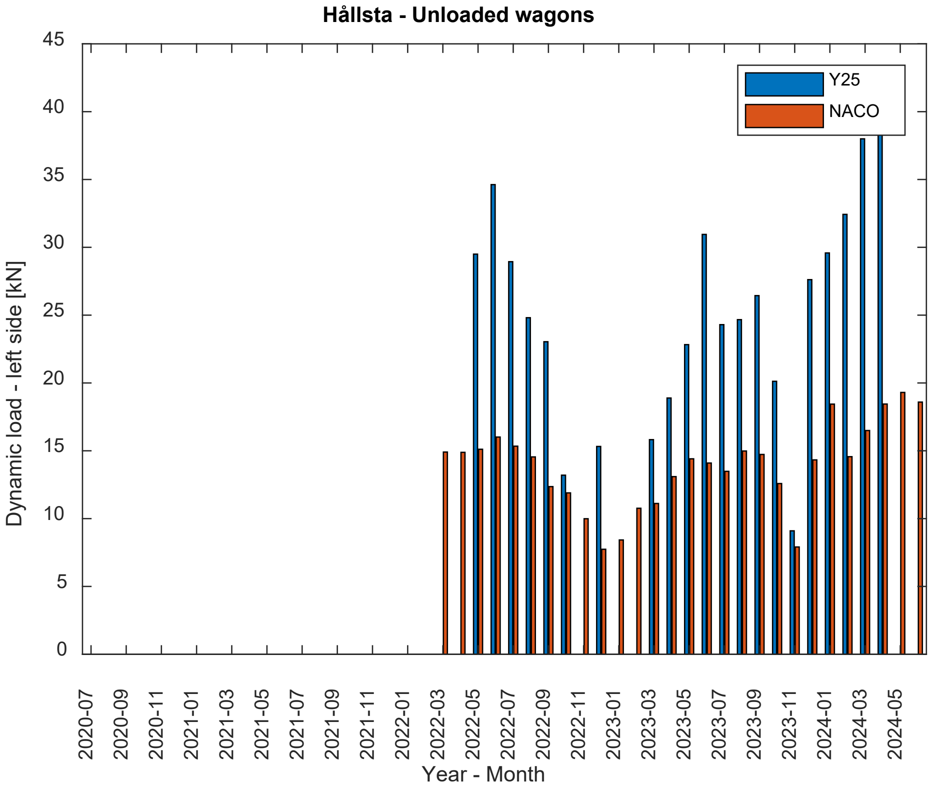
[6] NACO bogies primarily operate in the southern circuit, which also has a much gentler topography. Braking accelerates the wear of the wheel tread, which partly can also explain differences in dynamic loads generated by the NACO and Y25 bogies.


Hållsta - Unloaded wagons
Number of axles
10000
5000
0
2020-07
2020-09
2020-11
2021-01
2021-03
2021-05
2021-07
2021-09
2021-11
2022-01
2022-03
2022-05
2022-07
2022-09
2022-11
2023-01
2023-03
2023-05
2023-07
2023-09
2023-11
2024-01
2024-03
2024-05
Year - Month
Hållsta - Unloaded wagons
Mean speed [km/h]
100
50
0
Y25
NACO
Year - Month

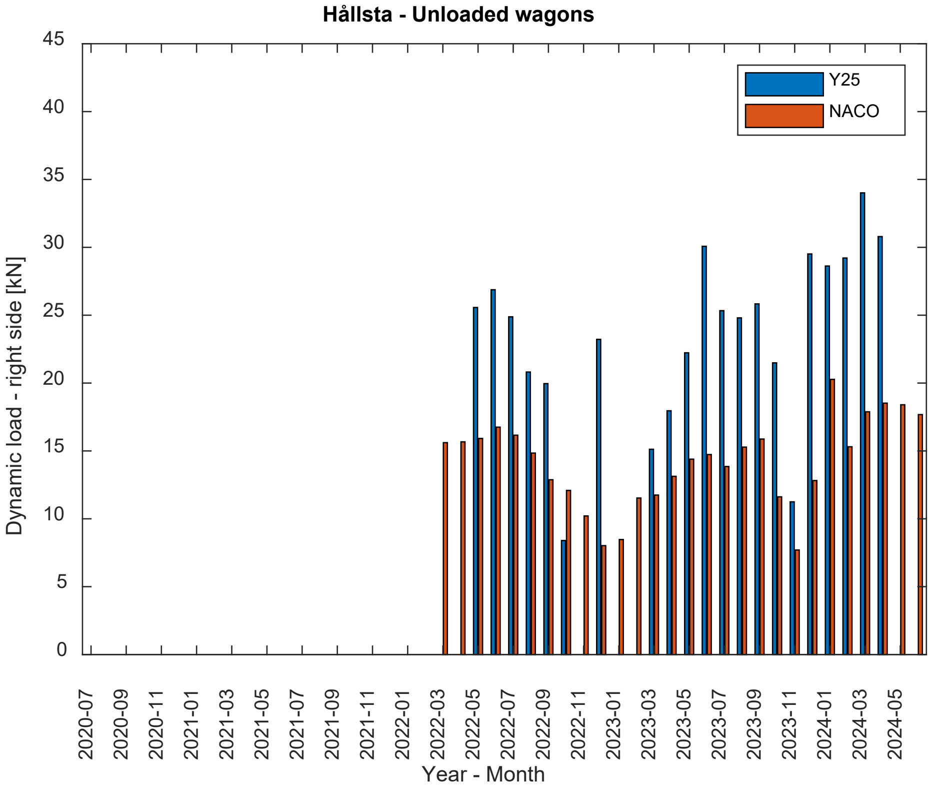
(a)


Hållsta - Unloaded wagons
Mean axle load [tonnes]
6
5
4
3
2
1
0
Y25
NACO
2020-07
2020-09
2020-11
2021-01
2021-03
2021-05
2021-07
2021-09
2021-11
2022-01
2022-03
2022-05
2022-07
2022-09
2022-11
2023-01
2023-03
2023-05
2023-07
2023-09
2023-11
2024-01
2024-03
2024-05
Year - Month

(b)

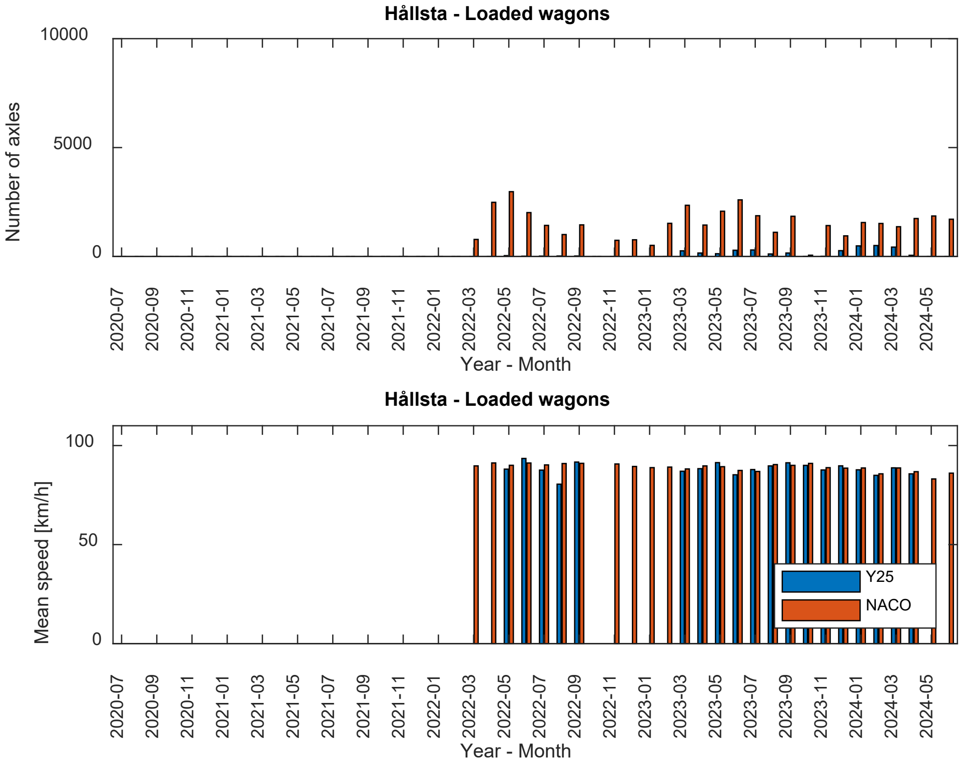


(c)

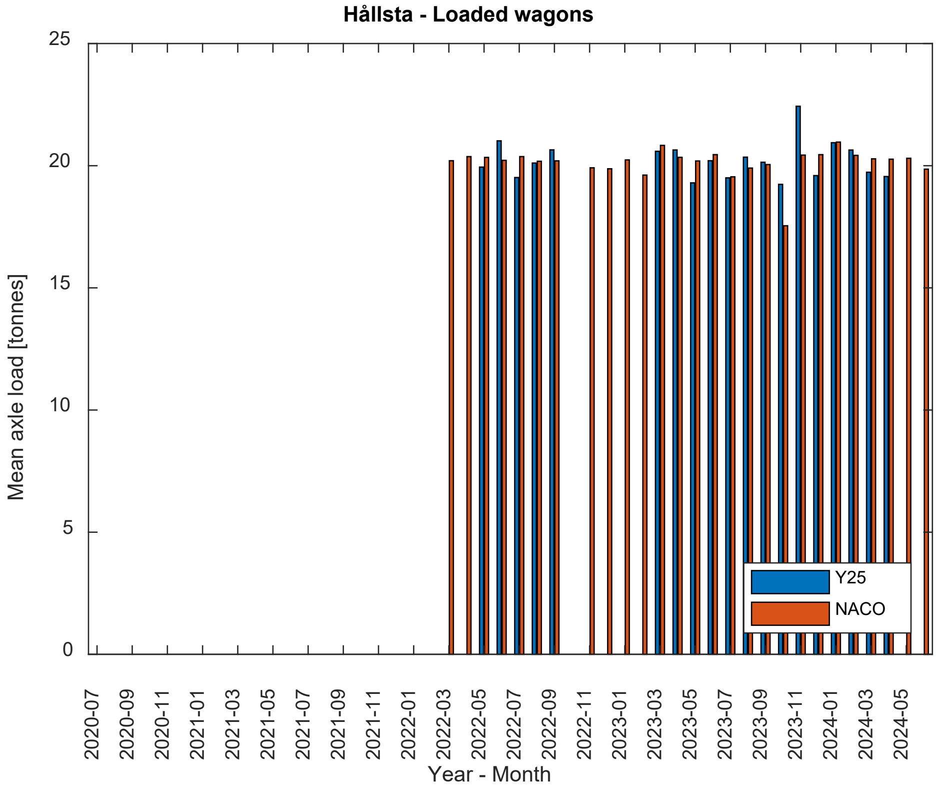


(d)

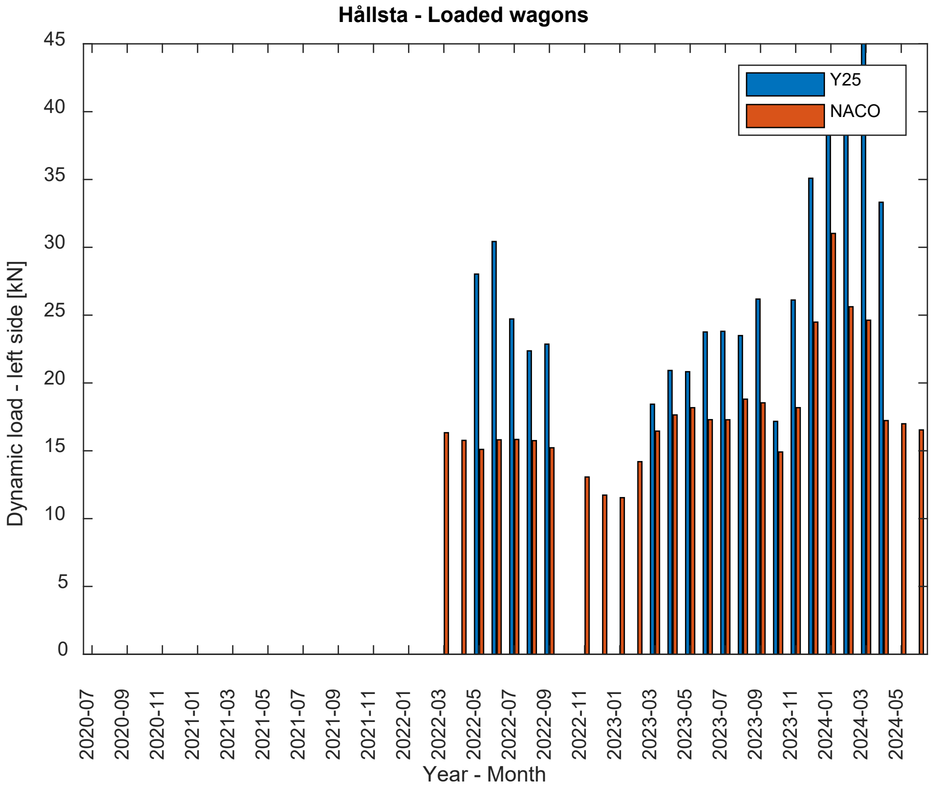
Figure 6.9 Long-term measurement in the PHOENIX MDS detector at Hållsta – unloaded steel shuttle wagons: (a) Number of measured axles with either Y25 or NACO bogies, and mean vehicle speed. (b) Mean axle load. (c) Mean of dynamic loads per wheel – left side, (d) Mean of dynamic loads per wheel – right side.


Hållsta - Loaded wagons
Number of axles
10000
5000
0
Year - Month
Hållsta - Loaded wagons
Mean speed [km/h]
100
50
0
Y25
NACO
Year - Month
2020-07
2020-09
2020-11
2021-01
2021-03
2021-05
2021-07
2021-09
2021-11
2022-01
2022-03
2022-05
2022-07
2022-09
2022-11
2023-01
2023-03
2023-05
2023-07
2023-09
2023-11
2024-01
2024-03
2024-05

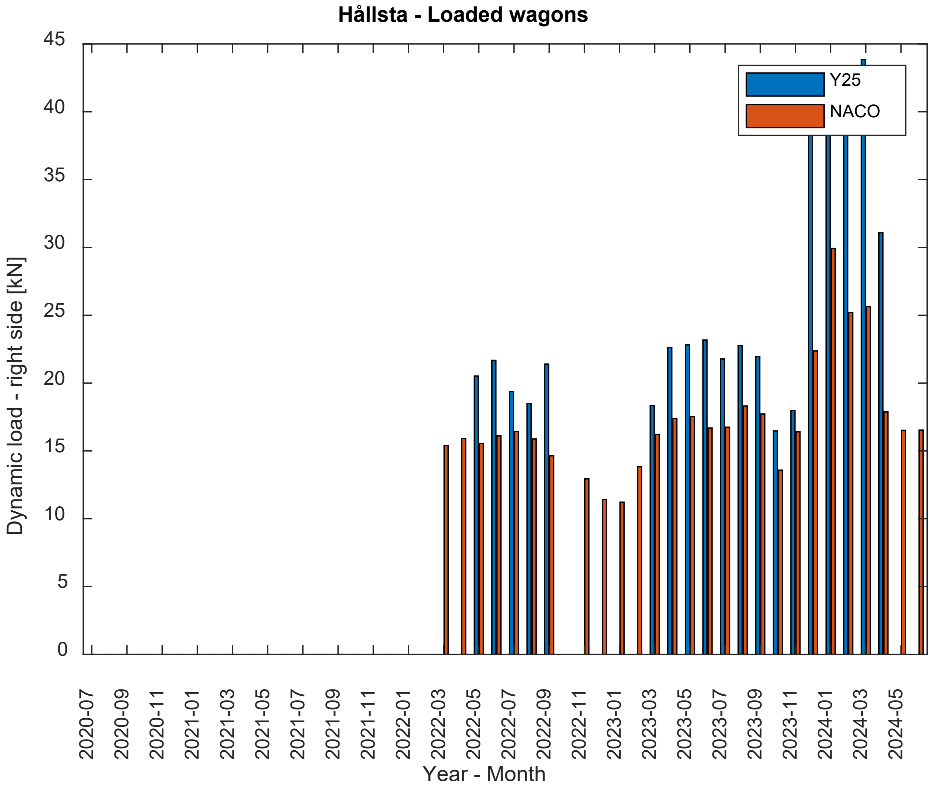
(a)


Hållsta - Loaded wagons
Mean axle load [tonnes]
25
20
15
10
5
0
Y25
NACO
Year - Month
2020-07
2020-09
2020-11
2021-01
2021-03
2021-05
2021-07
2021-09
2021-11
2022-01
2022-03
2022-05
2022-07
2022-09
2022-11
2023-01
2023-03
2023-05
2023-07
2023-09
2023-11
2024-01
2024-03
2024-05

(b)



(c)



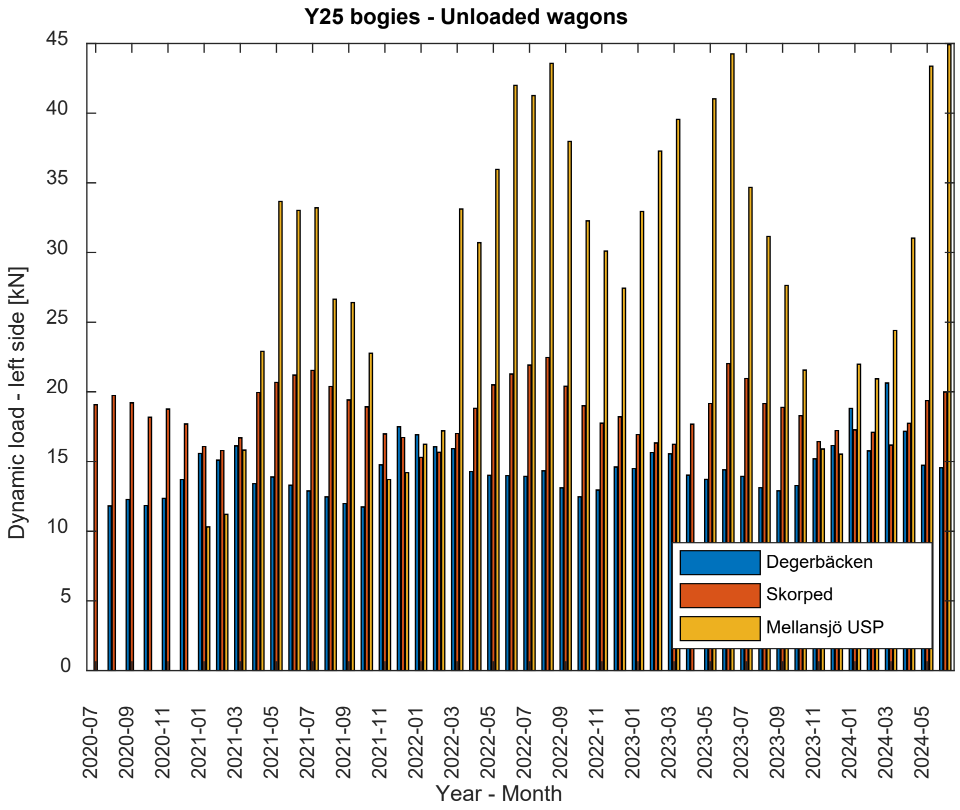
(d)

Figure 6.10 Long-term measurement in the PHOENIX MDS detector at Hållsta – loaded steel shuttle wagons: (a) Number of measured axles with either Y25 or NACO bogies, and mean vehicle speed. (b) Mean axle load. (c) Mean of dynamic loads per wheel – left side, (d) Mean of dynamic loads per wheel – right side.

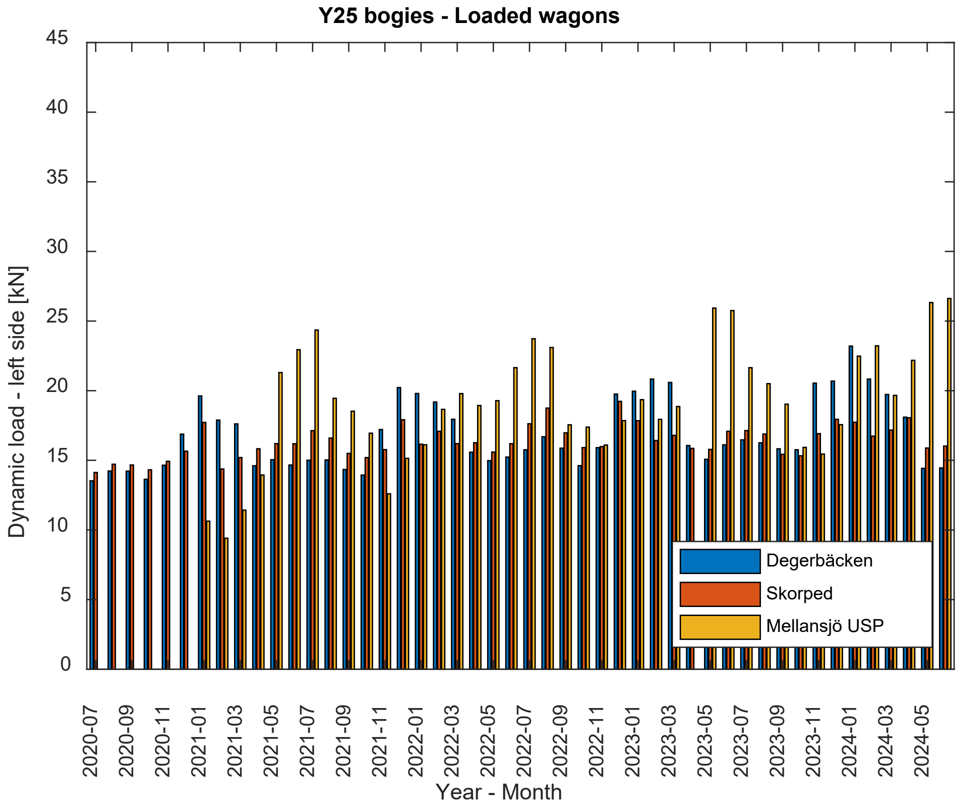
6.9 Case study 2: Dynamic loads at Degerbäcken, Skorped and Mellansjö USP

For both unloaded and loaded wagons, dynamic wheel loads measured by the detectors at Degerbäcken, Skorped and Mellansjö USP are compared in Figures 6.11 (Y25 bogies) and 6.12 (NACO bogies).

- It is observed that the measured dynamic loads are generally higher in the detector at Mellansjö than in the detectors at Degerbäcken and Skorped, particularly for the unloaded wagons.
- For the unloaded Y25 wagons, the dynamic loads are higher in the detector at Skorped than at Degerbäcken. This could possibly be due to the observed irregularities in track geometry and track stiffness at Skorped.
- For the loaded wagons (both Y25 and NACO), there is good agreement between dynamic loads measured in the detectors at Degerbäcken and Skorped.
- The reason for the seasonal variation in dynamic loads, particularly for the unloaded wagons in the detector at Mellansjö but also to some extent in the detector at Skorped, is unknown.

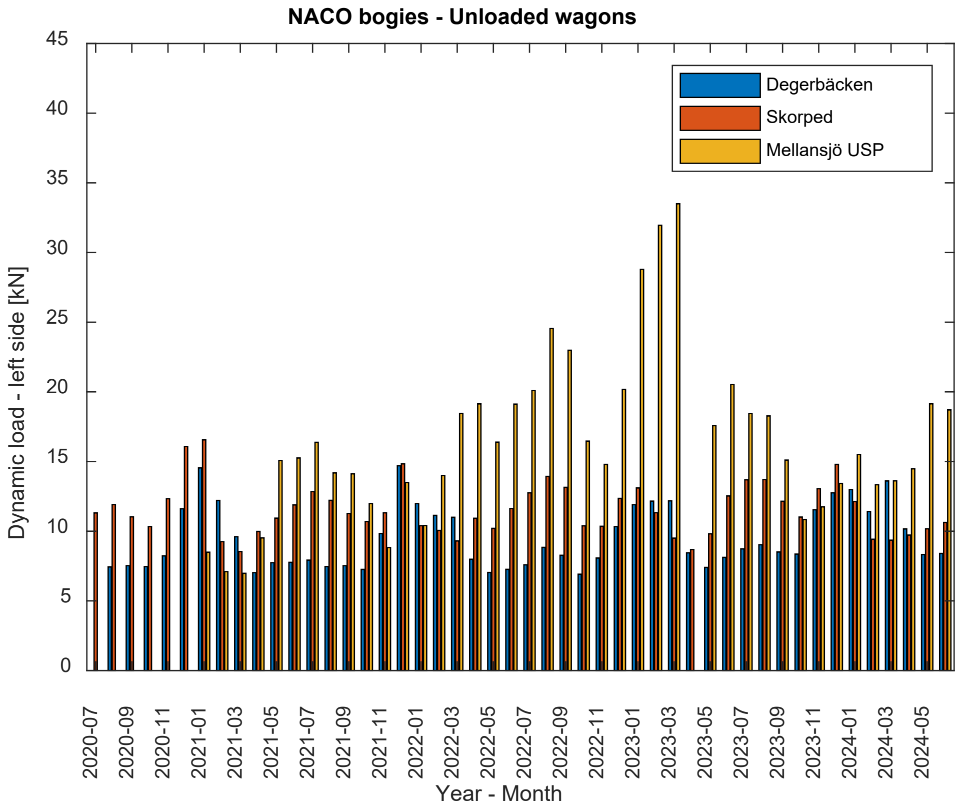


(a)

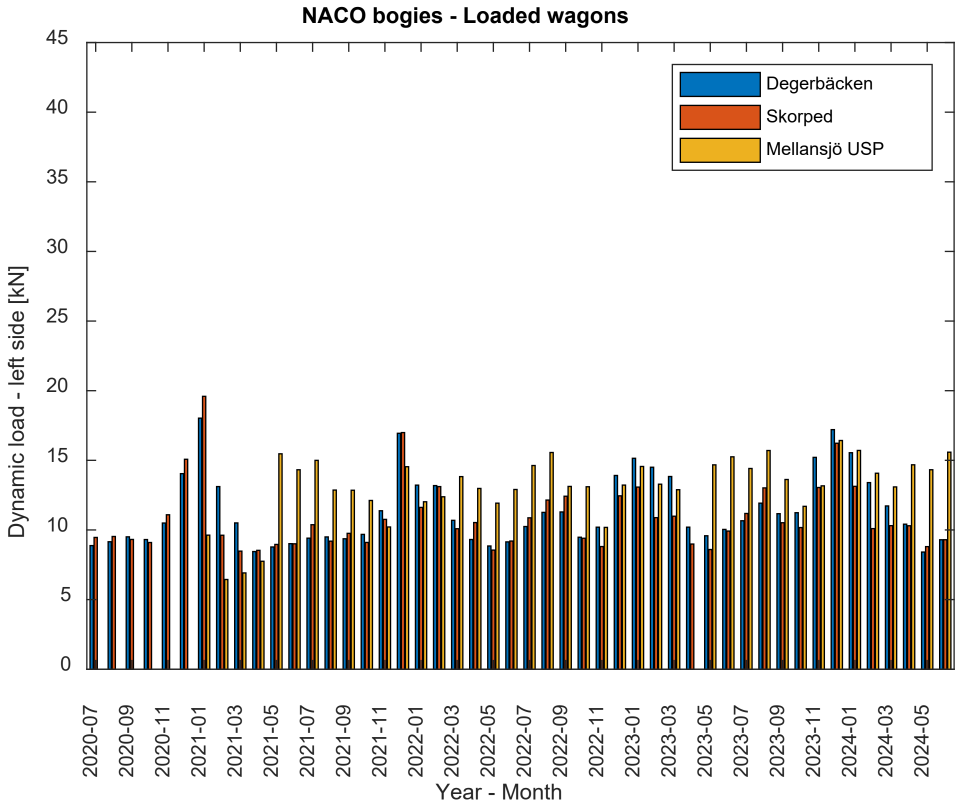


(b)

Figure 6.11 Long-term measurement of dynamic loads in the Schenck detectors at Degerbäcken and Skorped and PHOENIX MDS detector at Mellansjö USP – steel shuttle wagons with Y25 bogies: (a) Unloaded wagons, (b) Loaded wagons.



(a)



(b)

Figure 6.12 Long-term measurement of dynamic loads in the Schenck detectors at Degerbäcken and Skorped and PHOENIX MDS detector at Mellansjö USP – steel shuttle wagons with NACO bogies: (a) Unloaded wagons, (b) Loaded wagons.

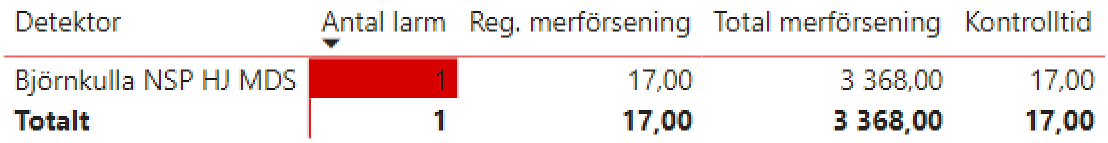
7 Consequences of wheel damage – SJ

A detector alarm can lead to a major traffic disturbance in the railway system resulting in customer delays and associated costs.

7.1 Wheel load data

Data from Trafikverket's wheel impact load detectors is an important source to monitor the wheel condition on SJ's fleets, and an efficient way to reduce the number of traffic disruptions. Based on issued warning alarms, maintenance activities can be planned, and traffic interruptions and unscheduled maintenance stops can be avoided.

Nevertheless, depending on track section and time of the day, a detector alarm leading to a short stop for the train with the damaged wheel may result in a major traffic disturbance for the complete railway system. For example, in peak hours, a relatively short train stop ('Reg. merförsening') of 17 minutes to investigate a damaged wheel may result in an accumulation of thousands (3368) of delay minutes for the surrounding trains that are affected by the train stop, see the example in Figure 7.1.



Detektor	Antal larm	Reg. merförsening	Total merförsening	Kontrolltid
Björnkulla NSP HJ MDS	1	17,00	3 368,00	17,00
Totalt	**1**	**17,00**	**3 368,00**	**17,00**

Figure 7.1. Example of accumulated train delay minutes due to one train stop caused by an alarm from the detector at Björnkulla[7].

7.2 Number of stopped trains and delays

Generally, very few SJ trains are stopped due to wheel damage alarms. In 2023, only one train was stopped. This is due to an active condition-based maintenance strategy involving an internal procedure for monitoring of measured load data, see Section 7.2.1. Nevertheless, major traffic disturbances would be the result should there occur a wheel flat due to an unreleased parking brake (normally due to human error).

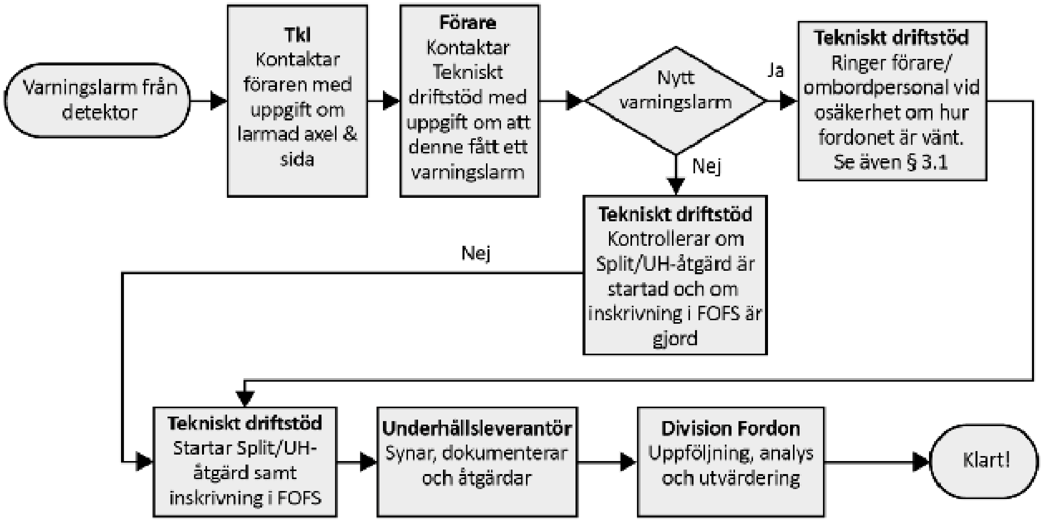
In particular, the regulation for wheel flats is a concern for SJ AB. This is because according to Trafikverket's regulations (TDOK 2020:0074) there is a stopping limit in terms of maximum wheel flat length set at 60 mm. If a detected wheel flat is 60 mm or longer, the train is stopped and is not allowed to continue. This is independent of axle load, and without the possibility to continue at reduced speed.

7.2.1 Active condition-based maintenance

Since 2013, SJ AB has an established action plan setting out from warning alarms received from the infrastructure manager (IM) Trafikverket, see Figure 7.2.

---

[7] *'Reg. merförsening' = Registered delay time for the train that set off the detector alarm. 'Total merförsening' = Reg. merförsening' plus delay time for all other surrounding trains that are affected by the stopped train. 'Kontroll tid' = Time for the stopped train to investigate the alarming wheel/wheels.*

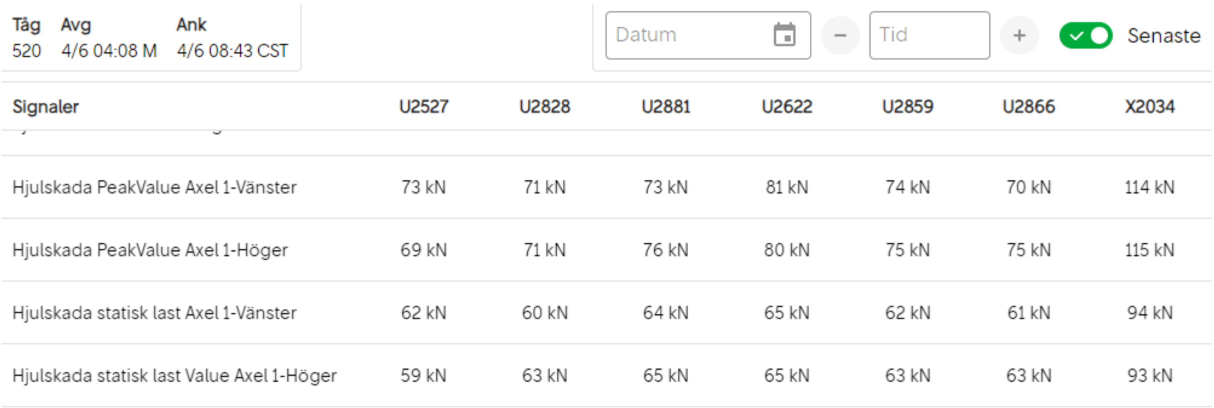


Figur 1. Flödesschema för hantering av varningslarm

Figure 7.2. Procedure according to SJF 400.130.1 in case of an alarm from a wheel impact load detector.

According to Figure 7.2, the train driver is notified by the infrastructure manager (IM) train dispatch officer that a warning alarm has occurred. The driver then reports to the operational technical support centre who issues a work order in the maintenance system. The maintenance organisation inspects the affected wheel and takes appropriate actions, i.e. wheel turning or wheel removal if the remaining wheel diameter is too small. In parallel, all measured data from all detector passages is continuously received via a subscription service from the IM. The measured data is processed in SJ's condition-based maintenance monitoring system 'Imperium', see the example in Figure 7.3 illustrating a case where all wheels are in good condition (no alarm). For the given combination of vehicle and wheelset type, the adopted intervention thresholds calling for maintenance are then applied.

To specifically monitor wheel degradation and trends, a Power BI-report has been generated, see Figure 7.4. This report is used by rolling stock department analysis team.



Tåg	Avg	Ank
520	4/6 04:08 M	4/6 08:43 CST

Signaler	U2527	U2828	U2881	U2622	U2859	U2866	X2034
Hjulskada PeakValue Axel 1-Vänster	73 kN	71 kN	73 kN	81 kN	74 kN	70 kN	114 kN
Hjulskada PeakValue Axel 1-Höger	69 kN	71 kN	76 kN	80 kN	75 kN	75 kN	115 kN
Hjulskada statisk last Axel 1-Vänster	62 kN	60 kN	64 kN	65 kN	62 kN	61 kN	94 kN
Hjulskada statisk last Value Axel 1-Höger	59 kN	63 kN	65 kN	65 kN	63 kN	63 kN	93 kN

Figure 7.3. Detector data extracted from the maintenance monitoring system 'Imperium' for train number 520. Peak loads and mean loads for the left and right wheels on the leading axle

for the different vehicles of an X2 trainset. The numbers Uxxxx are SJ's numbers for vehicle individuals. The low load magnitudes indicate that all wheels are in good condition.

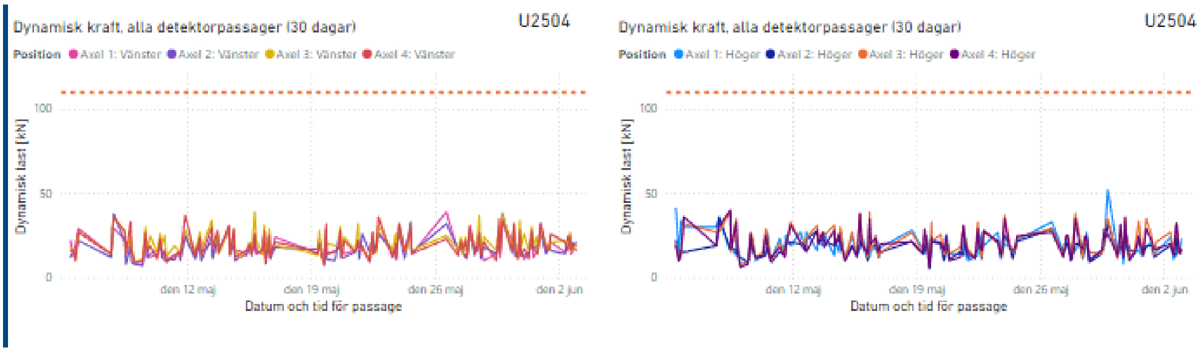


Figure 7.4. Measured dynamic load per wheel in different detectors over 30 days. Extracted from the maintenance monitoring system 'Imperium' and visualised in a Power BI report.

7.2.2 IM and RU periodic joint analysis

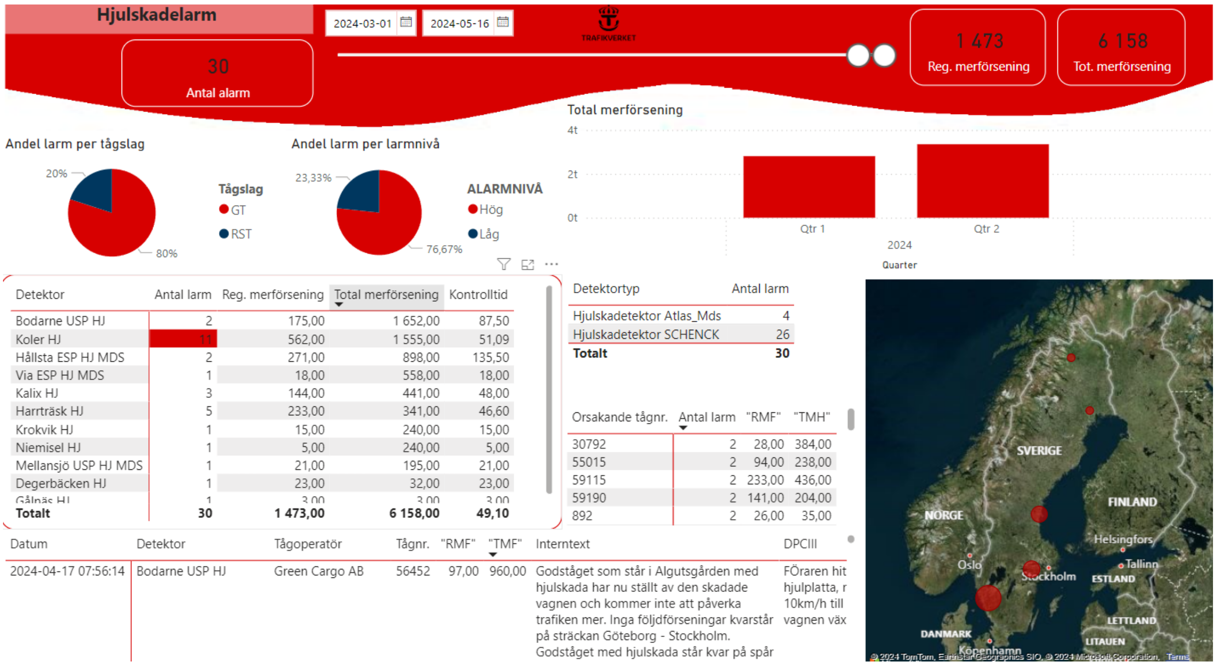
Quarterly (four times per year), the IM and the Railway Undertakers (RU) meet in a forum named 'Industry common management detectors' (Branschgemensam förvaltning Detektorer). To obtain a common understanding of the situation and aiming to focus on the incidences that give the highest negative impact in terms of traffic interruptions, a Power BI tool named 'Common situation picture' (Gemensam lägesbild) has been developed, see Figure 7.5. The tool uses two data sources: 1) detector alarms (DPCIII), and 2) traffic delays (LUPP). These two data sources are combined to filter the detector alarms that have resulted in the incidents that have caused the most severe disturbances in terms of delay minutes.

In the example in Figure 7.5, the following information can be extracted:

- During the period 2024-03-01 – 2024-05-16, there were in total 30 alarms leading to 1473 delay minutes. The accumulated number of delay minutes from 2024-01-01 is 6158 minutes.
- 20% of the 30 alarms were generated by passenger trains, while 80% were generated by freight trains.
- 23.3% of the 30 incidents were low-level alarms (280 kN), while 76.67% were high-level alarms (350 kN).
- Data has been collected from 30 detectors (26 of the type Schenck and 4 of the type ATLAS MDS[8]).
- The number of alarms per detector and resulting delay minutes per detector. In the studied time period, two alarms in the detector at Bodarne generated 175 delay minutes, while the 11 alarms in the detector at Koler generated 562 delay minutes.
- The map illustrates the detector sites where the alarms were generated.
- The trains, identified by their train number, that generated the alarms.

---

[8] Same as zentrac.



Detektor	Antal larm	Reg. merförsening	Total merförsening	Kontrolltid
Bodarne USP HJ	2	175,00	1 652,00	87,50
Koler HJ	11	562,00	1 555,00	51,09
Hållsta ESP HJ MDS	2	271,00	898,00	135,50
Via ESP HJ MDS	1	18,00	558,00	18,00
Kalix HJ	3	144,00	441,00	48,00
Harrträsk HJ	5	233,00	341,00	46,60
Krokvik HJ	1	15,00	240,00	15,00
Niemisel HJ	1	5,00	240,00	5,00
Mellansjö USP HJ MDS	1	21,00	195,00	21,00
Degerbäcken HJ	1	23,00	32,00	23,00
Gålnäs HJ	1	3,00	3,00	3,00
Totalt	**30**	**1 473,00**	**6 158,00**	**49,10**

Detektortyp	Antal larm
Hjulskadetektor Atlas_Mds	4
Hjulskadetektor SCHENCK	26
Totalt	**30**

Orsakande tågnr.	Antal larm	"RMF"	"TMH"
30792	2	28,00	384,00
55015	2	94,00	238,00
59115	2	233,00	436,00
59190	2	141,00	204,00
892	2	26,00	35,00

Datum	Detektor	Tågoperatör	Tågnr.	"RMF"	"TMF"	Interntext	DPCIII
2024-04-17 07:56:14	Bodarne USP HJ	Green Cargo AB	56452	97,00	960,00	Godståget som står i Algutsgården med hjulskada har nu ställt av den skadade vagnen och kommer inte att påverka trafiken mer. Inga följdförseningar kvarstår på sträckan Göteborg - Stockholm. Godståget med hjulskada står kvar på spår	FÖraren hit hjulplatta, r 10km/h till vagnen väx

Figure 7.5. Example of 'Common situation picture' for the period 2024-03-01 – 2024-05-16.

7.3 Costs

Besides the company cost for compensation to affected customers, there are secondary effects such as due to the inaccessibility of vehicles (trains) that are out of production.

The cost for calling out the "recovery contingency crew(s)", i.e. the maintenance company contracted by the region, for assessment of a wheel damage and application of temporary maintenance actions varies substantially. The staff must be available at all times, 24 hours a day, 7 days a week. On average, the cost per occasion is € 2500 – 3500. However, if the vehicle needs to be placed on a trolley to be towed to a depot with maintenance abilities there is an additional cost for drivers and rental of the trolley. As an example, the cost for remediate maintenance actions and rental of trolley (several days) for towing to a depot with maintenance abilities is € 20 000 excluding the internal cost for drivers and other resources. In addition to this, the towing of non-functional vehicles, particularly using trolleys, mandates very low speeds[9], which seriously impacts the capacity of the railway line. Consequently, transportation to maintenance facilities is often delayed due to a lack of empty slots in the timetables, which in turn adds to the total downtime (unavailability) for the vehicle

There is also a socioeconomic cost for passenger and goods delays (ASEK) that needs to be considered and should also lead to decision support to make investments in the railway system. Based on the registered delay time, calculations of the socioeconomic costs can be made using the software LUPP from Trafikverket Lupp uppföljningssystem - Bransch (trafikverket.se).

---

[9] Towing speeds may, in extreme cases, be as low as 10 km/h. Since several of the main lines in Sweden currently operate at near maximum capacity, any reduction in speed below the average train speeds will constitute a challenge for train dispatching. Dispatchers are in general reluctant to allowing such movements.

8 References

1. S. Iwnicki, J.C.O. Nielsen, G. Tao, Out-of-round railway wheels and polygonisation, Vehicle System Dynamics, 61(7), 1785–1828, 2023
2. UIC, Prevention and mitigation of derailment (PMD), IRS 70729, 2019
3. M. Asplund, Larmnivåer hjulskadedetektor (Alarm levels for wheel impact load detector, in Swedish), Trafikverket, TRV 2020:96962 v 4.0, 2023
4. Trafikverket, Detektorer. Hantering av larm samt åtgärder efter konstaterade skador (Detectors. Handling of alarms and measures following ascertained damages, in Swedish), TDOK 2020:0074 v2.0, 2021
5. R. Müller, M. Speyerer, Multirail® Wheelscan Banverket, Schweden Version 1.1, Schenck Process GmbH, Darmstadt, 70 pp, 2006
6. M. Rantatalo, Driving point measurement of a railway wheel impact detector, Measurement report, 6 pp, September 2021
7. D. Venekamp, PHOENIX^{MDS} WIM/WDD Function Description Revision 03.1, voestalpine SIGNALING Siershahn GmbH, Siershahn, 37 pp, 2019
8. Trafikverket, Detektorer – Krav vid val av detektorplats (Detectors – Regulations for specification of detector position, in Swedish), TDOK 2013:0689 v3.0, 8 pp (+ 24 pp appendices), 2020
9. Trafikverket, DETEKTORER; Förutbestämt underhåll detektoranläggningar i spårmiljö järnväg (DETECTORS; Scheduled maintenance detector facilities in railway track environment, in Swedish), TDOK 2019:0478 v1.0, 28 pp (+ 144 pp appendices), 2019
10. M. Fernandez Arango, PHOENIX^{MDS} WIM/WDD Maintenance Manual Revision 01.1, voestalpine SIGNALING Siershahn GmbH, Siershahn, 55 pp, 2018
11. E. Berggren, Verification of new wheel flat detectors – SCHENCK (2007-02-01), Banverket Report BBS 2006/27, 12 pp (+ 18 appendices)
12. E. Berggren, Verification of new wheel flat detectors – BAAS (2007-02-14), Banverket Report BBS 2006/28, 14 pp (+ 15 appendices)
13. A. Ekberg, B. Paulsson, D-RAIL – Konsten att inte spåra ur (D-RAIL – The art of not derailing, in Swedish), 28 pp, 2015
14. K. Mattsson, Wheel–rail impact loads generated by wheel flats – Detector measurements and simulations, MSc thesis, Department of Mechanics and Maritime Sciences, Chalmers University of Technology, Gothenburg, Sweden, 53 pp + Appendices, 2023
15. K. Mattsson, J.C.O. Nielsen, L. Fehrlund, M. Maglio, T. Vernersson, On wayside detector measurement of wheel–rail impact loads induced by wheel flats – Data analysis, alarm levels and regulations. In J. Pombo (Editor), Proceedings of the Sixth International Conference on Railway Technology: Research, Development and Maintenance, Civil-Comp Press, Edinburgh, UK, Online volume: CCC 7, Paper 7.10, 2024, doi:10.4203/ccc.7.7.10
16. J.C.O. Nielsen, E.G. Berggren, A. Hammar, et al., Degradation of railway track geometry – Correlation between track stiffness gradient and differential settlement,

Proceedings of the Institution of Mechanical Engineers, Part F Journal of Rail and Rapid Transit, 234(1), 108–119, 2020

17. Trafikverket, BVH 524.100 - Katalog över rälsfel (BVH 524.100 - Catalogue of rail damage, in Swedish), TDOK 2014:0598 v1.0, 115 pp, 2015
18. M. Asplund, Hjulskada som orsakade momentant rälsbrott mellan Boden C och Sävastklinten 14 feb. 2019 (Wheel flat which caused an instant rail break between Boden C and Sävastklinten on February 14th, 2019, in Swedish), Trafikverket PM, 4 pp, 2019
19. Trafikverket, Rälsfel och rälsbrott 2023 Årlig uppföljningsrapport (Rail defects and rail damage 2023 annual follow-up report, in Swedish), 15 pp, 2024
20. Trafikverket, Punktlighet och störningar i järnvägstrafiken, 2013–2023 (Punctuality and disturbances in railway traffic, 2013-2023, in Swedish), 37 pp, 2024
21. Dings, P. and Dittrich, M.G.: Roughness on Dutch railway wheels and rails. Journal of Sound and Vibration 193 (1995), pp. 103–112

.

Appendix

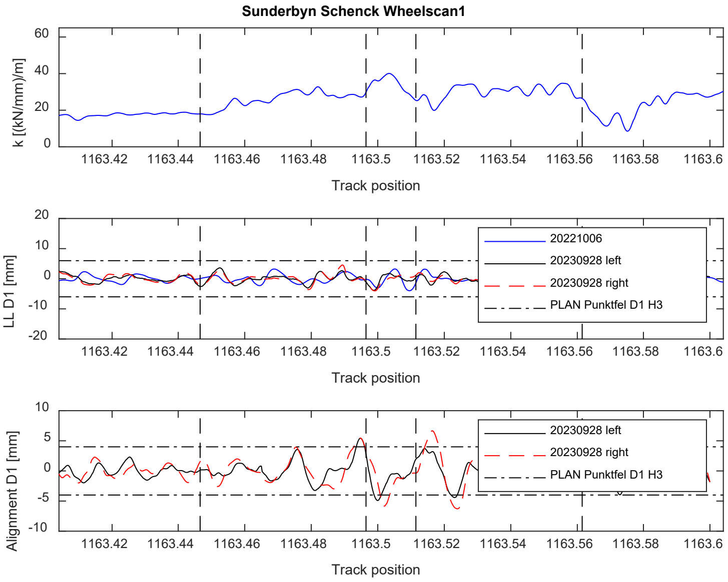


Figure A.1 Foundation stiffness, longitudinal level (bandpass filtered 1 – 25 m) and alignment measured in the WILD at Sunderbyn. See also caption to Figure 4.10.

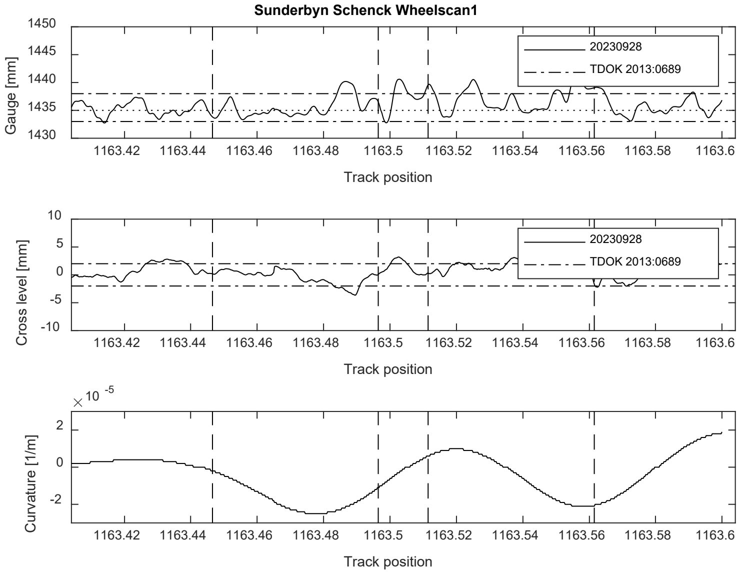


Figure A.2 Gauge, cross level and curvature over a distance of 200 m in the WILD at Sunderbyn. See also caption to Figure 4.11.

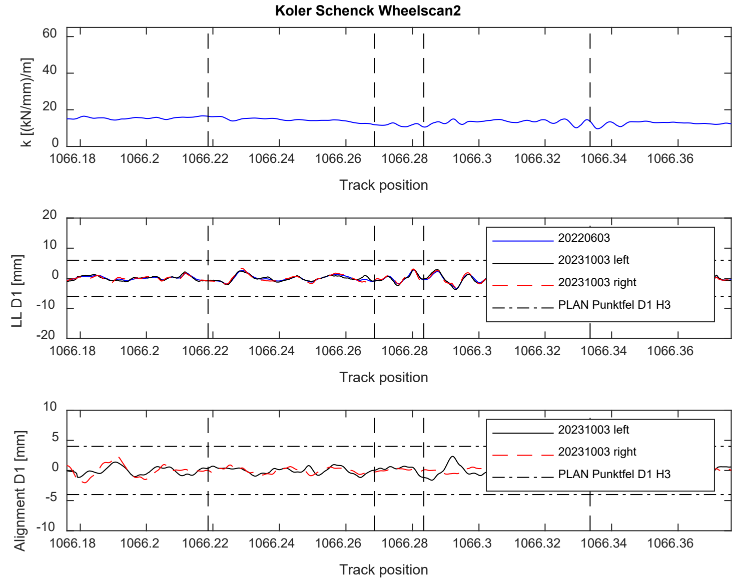


Figure A.3 Foundation stiffness, longitudinal level (bandpass filtered 1 – 25 m) and alignment measured in the WILD at Koler. See also caption to Figure 4.10.

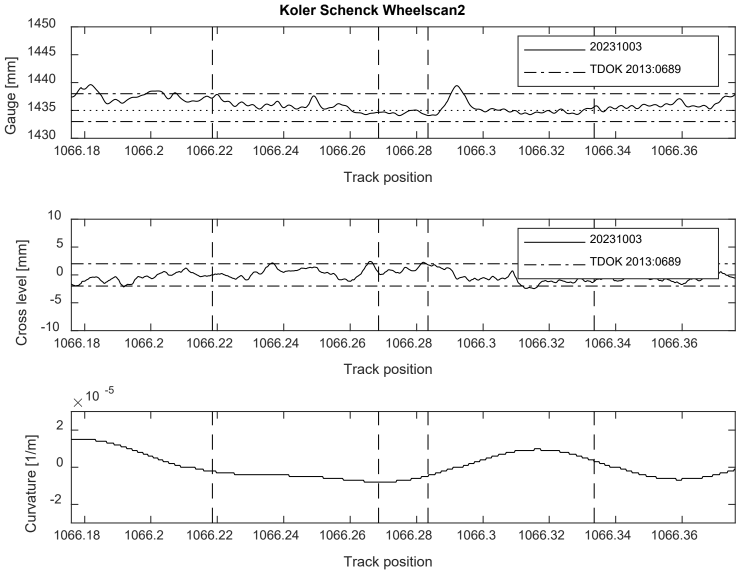


Figure A.4 Gauge, cross level and curvature over a distance of 200 m in the WILD at Koler. See also caption to Figure 4.11.

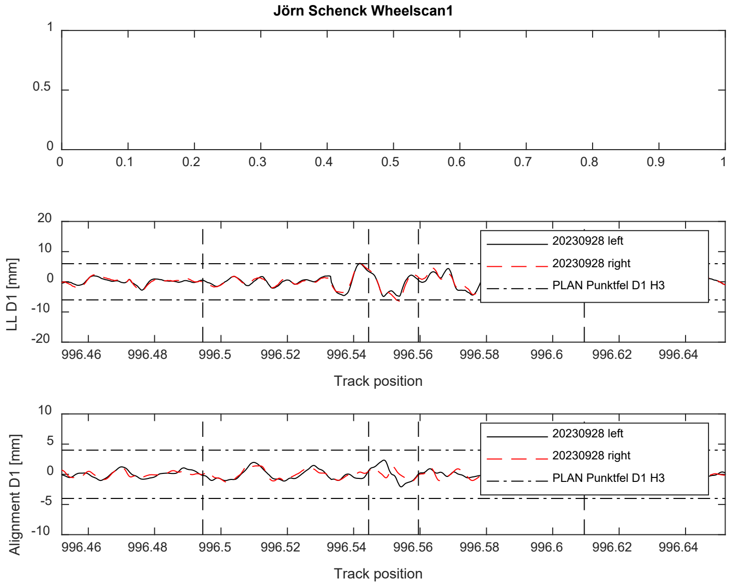


Figure A.5 Longitudinal level (bandpass filtered 1 – 25 m) and alignment measured in the WILD at Jörn (no measurement of track stiffness). See also caption to Figure 4.10.

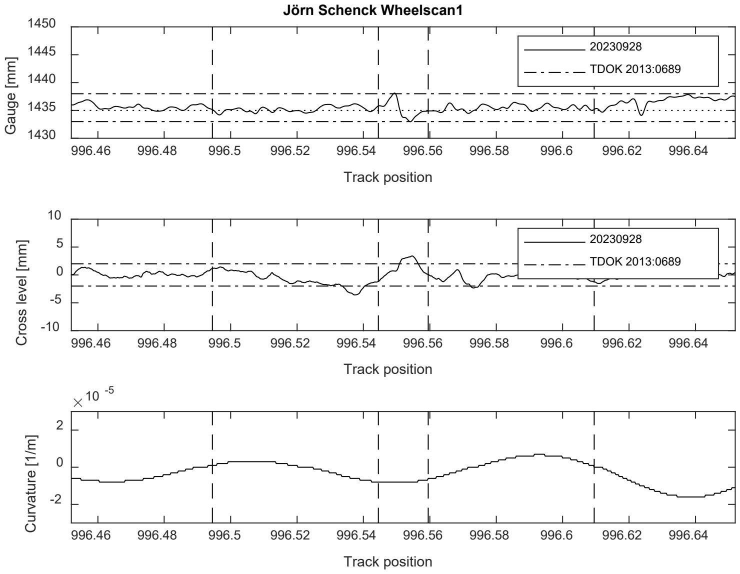


Figure A.6 Gauge, cross level and curvature over a distance of 200 m in the WILD at Jörn. See also caption to Figure 4.11.

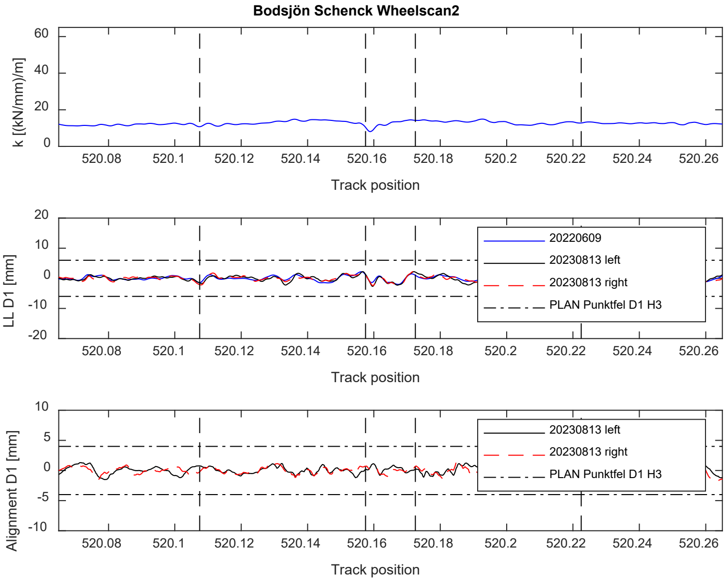


Figure A.7 Foundation stiffness, longitudinal level (bandpass filtered 1 – 25 m) and alignment measured in the WILD at Bodsjön. See also caption to Figure 4.10.

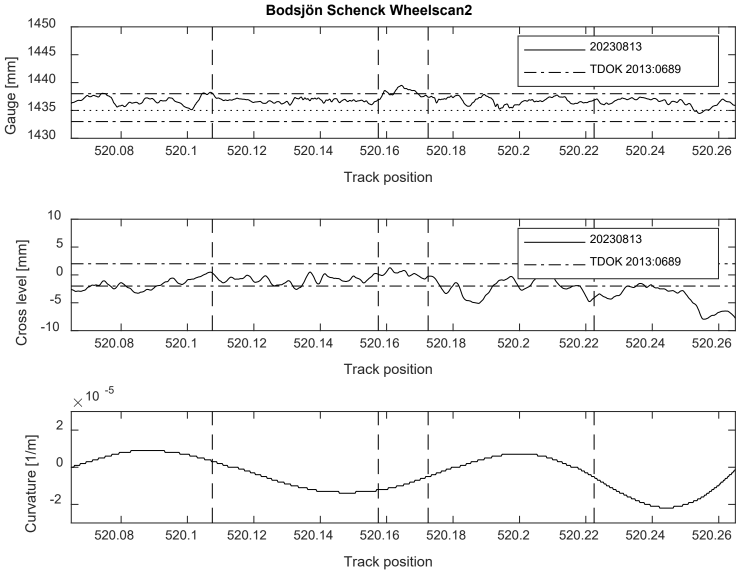


Figure A.8 Gauge, cross level and curvature over a distance of 200 m in the WILD at Bodsjön. See also caption to Figure 4.11.

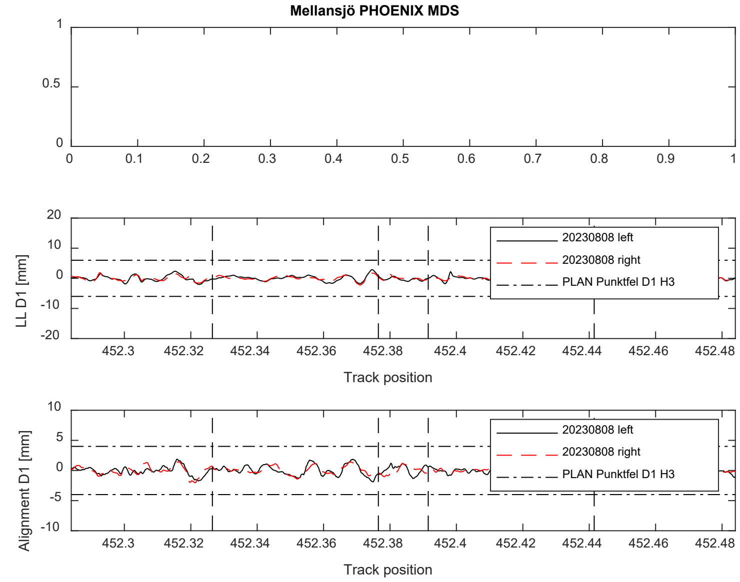


Figure A.9 Longitudinal level (bandpass filtered 1 – 25 m) and alignment measured in the WILD at Mellansjö (no measurement of track stiffness). See also caption to Figure 4.10.

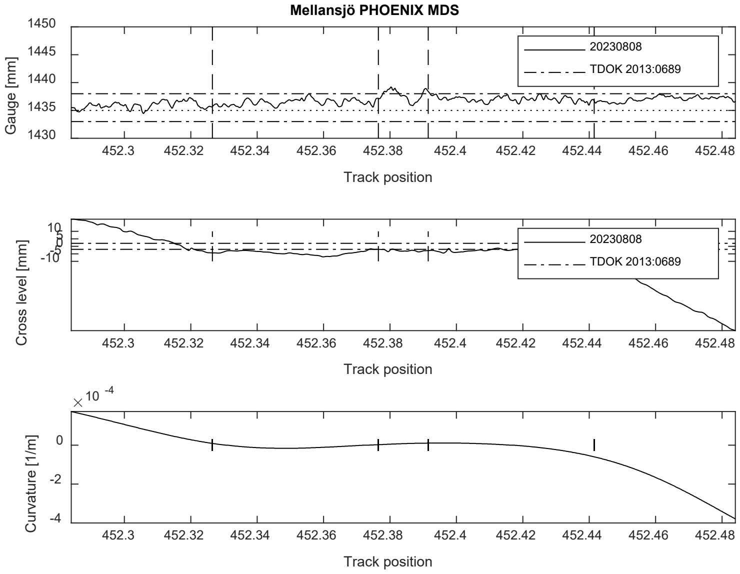


Figure A.10 Gauge, cross level and curvature over a distance of 200 m in the WILD at Mellansjö. See also caption to Figure 4.11.

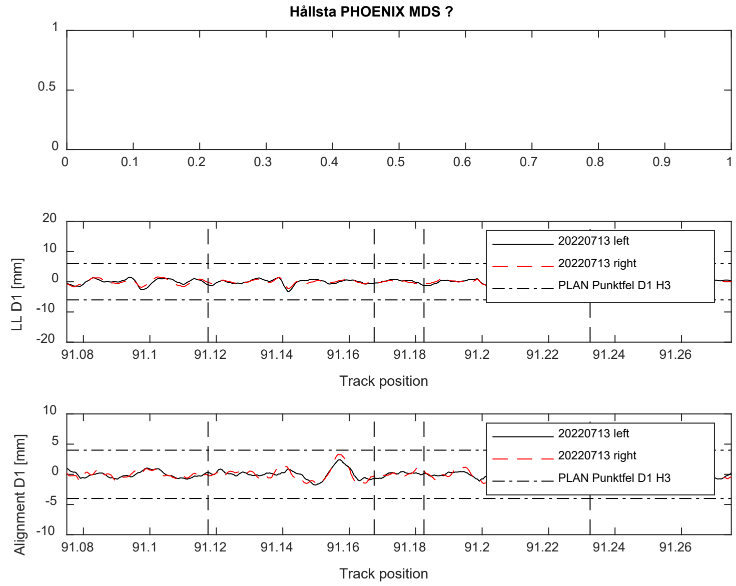


Figure A.11 Longitudinal level (bandpass filtered 1 – 25 m) and alignment measured in the WILD at Hållsta (no measurement of track stiffness). See also caption to Figure 4.10.

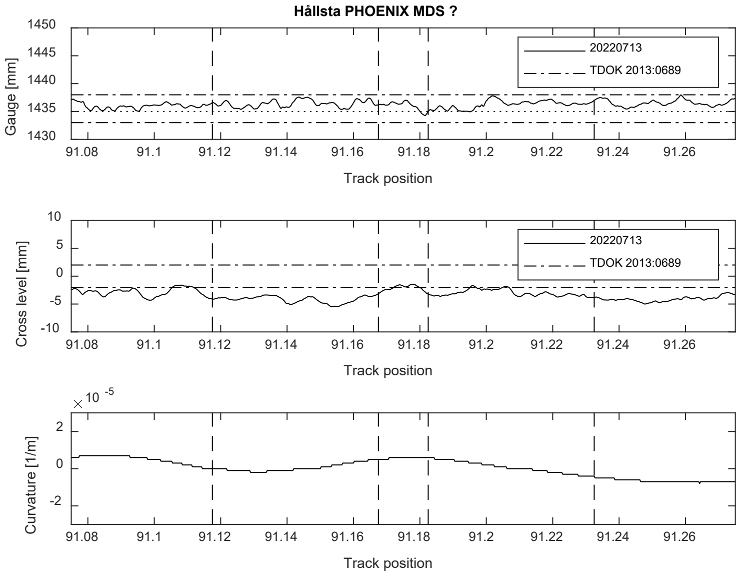


Figure A.12 Gauge, cross level and curvature over a distance of 200 m in the WILD at Hållsta. See also caption to Figure 4.11.