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Wheelset maintenance and monitoring

Current practices and strategies

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RAILWAY PROJECT REPORT 2024

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Cover: Outdoors wheelset storage at SweMaint AB in Gothenburg.

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Abstract

Railway wheelsets are a central component of railway vehicles. Maximizing the lifespan of wheelsets requires proper health monitoring and maintenance strategies. From a background in deterioration phenomena and the operational conditions of railway vehicles, this project gives an overview of maintenance and monitoring within the railway industry. This has been done through interviews with and visits to multiple industry actors. Practices within monitoring, maintenance, and possible business plans are highly variable, depending on operating conditions, involved actors, and the size and uniformity of the fleet. Potential benefits could be achieved through more cooperation and data sharing between actors, however this brings new challenges.

Contents

List of Figures	v
1 Introduction	1
2 Phenomena	2
2.1 Axle deterioration	2
2.1.1 Plain fatigue	2
2.1.2 Fretting	2
2.1.3 Corrosion	3
2.2 Wheels	3
2.2.1 Regular wear	3
2.2.2 Rolling contact fatigue	4
2.2.3 Thermal cracks	4
2.2.4 Wheel flats	4
2.3 Bearing failure	5
3 Operational conditions	6
3.1 Long distance and regional passenger trains	6
3.2 Operational conditions of freight wagons	6
3.3 Operational conditions of trams	7
4 Current practices	8
4.1 Industry structure	8
4.2 Wheel manufacturers	9
4.3 Maintenance centres	9
4.3.1 SweMaint AB	10
4.3.2 Železničné opravovne a strojárne Zvolen, s.r.o.	10
4.4 Train operators	12
4.5 Tram operators	13
4.5.1 Plzeňské městské dopravní podniky, a.s.	13
4.5.2 Dopravní podnik hl. m. Prahy, a.s.	14
4.5.3 Dopravný podnik Bratislava, a.s.	15
5 Discussion and conclusions	16
5.1 Monitoring	16
5.1.1 Automated measurements during operation	16
5.1.2 Inspections during maintenance visits	17

Contents

5.2	Maintenance	17
5.3	Interaction between actors	17
5.4	Final remarks	18
	Bibliography	21

List of Figures

4.1	Wheel lathe used at SweMaint.	10
4.2	Electromagnetizer used by ŽOSZV, made by ATG	11
4.3	Crack under ultraviolet light	11
4.4	Panametrics EPOCH 4 Ultrasonic Flaw Detector	12
4.5	Diagnostic station KOLTECH PZK2 taking measurements	15

1

Introduction

Rail transportation is a vital part of modern transport systems, moving freight and people across different distances in various climates. A key component of railway vehicles are wheelsets: an axle with wheels, bearings, and sometimes additional components like disc brakes or a gearbox. Various deterioration phenomena occur in a wheelset. These have different causes and occurrence rates that depend on vehicle type and operating conditions. Consequences are failures of varying severity. For safe and reliable operation, unexpected failures of wheelsets must be avoided. This can be done by monitoring different wheelset parameters automatically or by manual inspections and mitigation of non-conformities. These must be assessed in terms of severity and rapidity of consequences, and a maintenance plan must be established. The assessment and the maintenance strategy vary for different actors and operational scenarios. In addition, different actors have different contractual relations, legal responsibilities, and incentives.

This project gives a general overview of current practices of wheelset maintenance and monitoring in the industry, specifically with an EU focus. We also describe deterioration phenomena occurring in the wheels and axles on different types of rail vehicles.

To ensure a representative overview of the phenomena taking place in wheelsets of different vehicle types, a brief overview of the existing literature was performed. To get an example of current practices in the industry, we had multiple meetings with companies operating in different fields of the railway industry in different parts of the EU.

This report is structured as follows: Chapter 2 provides an overview of deterioration phenomena for wheelsets and their causes, consequences, possible monitoring, prediction, and mitigating actions. Chapter 3 characterizes different vehicle types and operational scenarios, specifically which phenomena each type is more sensitive to. It also investigates logistical opportunities and issues like out-of-service costs, depot availability, inspection regularity, and monitoring possibilities. Chapter 4 describes existing maintenance practices of different industry actors in different regions. It also contains a brief overview of the industry structure, legal responsibilities, and the structuring of contracts. Finally, some discussion and conclusions are given in chapter 5.

2

Phenomena

In this chapter, we will cover the most common deterioration phenomena occurring in axles and wheels.

2.1 Axle deterioration

Axle failures are one of the leading causes of severe derailments. This section will cover three main processes that can lead to axle failures: plain fatigue, fretting, and corrosion. However, we will not go into detail on other damage types. Acceptance limits are set by the European standard EN 15313:2016, section 6.2.5 [18].

2.1.1 Plain fatigue

Plain fatigue is material deterioration caused by rotating bending of the axle. This can be aggravated by vibrations, high dynamic forces and other phenomena. The area of failure is most often located close to the wheel hub or around a surface defect. The process starts off with small material defects, which over time grow into larger cracks. Crack growth is an exponential phenomena which is slow at first, but after cracks reach a critical length, their development becomes more rapid. For more information about crack growth, see [3, 14]. However, setting the critical length is not simple and is dependent on the operational conditions. Because of this, it is important to discover the crack quite early on in its development. If a large crack is discovered, the axle is usually replaced with a new one. Smaller surface cracks can be removed by grinding. The European standard does not allow for channels or cracks around the whole circumference of the axle, however it does not set a limit value for these defects. Possible inspection methods include ultrasonic testing and magnetic particle inspection [13].

2.1.2 Fretting

Fretting is a small oscillatory movement between two surfaces under load that leads to crack initiation. It typically occurs in the axle assembly due to lateral micro movements between the axle and the wheel. Heavy axle loads aggravate fretting. Consequences are material degradation, surface damage and resulting stress concentrations, leading to crack initiation. Inspection and defect removal methods are similar to those used for plain fatigue initiated cracks. Possible prevention actions are surface and material treatments. [13]

2.1.3 Corrosion

Corrosion also contributes to axle deterioration. Rust infected spots are more vulnerable to crack initiation caused by both of the above mentioned phenomena due to defected material. Some of these spots can be treated by regrinding and repainting. Rust removal is regulated by the European standard EN 15313:2016, section 6.2.5.1 [18].

2.2 Wheels

Wear and fatigue of railway wheels are important to monitor. They affect the performance of the wheels, and if left without proper maintenance could lead to a failure of the wheelset with catastrophic consequences. Thus, a good understanding and monitoring of wear is necessary.

2.2.1 Regular wear

Wheel wear is a general term referring to damage resulting in material loss of the wheel running surface. In this section we focus on slow-developing adhesive and abrasive wear distributed along the wheel profile, called ‘regular wear’. Other types of wear like rolling contact fatigue, wheel flats, and wheel out-of-roundness are covered separately.

Regular wear on railway wheels is the result of frictional forces in the contact area combined with sliding (creep). It is affected by the interaction of vehicle dynamics, wheel–rail friction, and mechanical properties of the wheel and rail material. It mainly results in two distinct wear regions: tread wear from regular running, traction and (tread) braking, and flange wear mainly from curve negotiation. Regular wear results in a changed wheel profile which affects the dynamic behaviour of the wheelset, in turn affecting ride comfort and performance. Wear interacts with other phenomena, either by reducing rates (e.g. wearing off initial cracks from plain fatigue or rolling contact fatigue), or increasing rates (e.g. a changed geometry worsening steering or periodic wear increasing dynamic loads) [10]. Additionally, a changed wheel profile will affect the derailment risk, and a changed flange geometry might not fit within the geometrical constraints of turnouts [11, 4].

Wear can be monitored by measuring the wheel profile either directly by mechanical probes or laser scanning, or indirectly e.g. through measuring axle box accelerations. Limit values are commonly set by safety related measures like flange width and height, for example in the European standard EN 15313:2016 section 6.2 [18]. However from a maintenance perspective, it is more suitable to quantify according to risks of subsequent wear and crack development [10]. Predicting wheel wear is complicated but doable. For an overview of different numerical methods, see for example chapter 6.5 in [4].

Since wear is affected by creepage and friction, mitigation methods are based on changing one of these components. Applying friction modifiers either from trackside devices or on-board applicators can reduce creep forces. Lubricating the flange or rail gauge corner in sharp curves can reduce flange wear. Wear-resistant wheel

profiles can affect wheelset dynamics as to minimize creepages and avoid two-point contact conditions. There are vehicle design-based mitigation methods like active steering or softer suspensions, but these are not very applicable from a maintenance perspective. Highly worn wheel profiles are fixed by reprofiling. For a more in-depth discussion, see chapter 6.6 in [4].

2.2.2 Rolling contact fatigue

Rolling contact fatigue (RCF) is a phenomenon that is triggered by the forces in the wheel-rail contact. RCF can be divided into surface-initiated RCF and subsurface-initiated RCF. Surface-initiated RCF is caused by frictional forces in the contact area between wheel and rail, where plastic deformation can occur if shear stresses are large enough. This can lead to crack initiation and growth. For wheelsets in use, it is very common for RCF to show, although cracks might be small enough to be deemed as acceptable, and may be worn off during continued operation. If surface-initiated RCF has developed far enough, reprofiling of the wheel is required. [8]

Cracks might also appear a few millimeters below the contact surface, where it usually starts at a material defect. The stresses resulting from the rolling contact load, combined with material defects, give stress concentrations that can result in cracks. If these grow and lead to failure, it usually means the crack branches to the wheel surface and detaches a piece of the wheel tread. The size of subsurface-initiated RCF cracks at failure vary, but can be at the size of 100 mm. [8]

2.2.3 Thermal cracks

The heating and cooling process of a railway wheel can cause plastic deformation that leads to cracks. These thermal loads are usually from tread brakes or wheel slip. When the wheel heats up, the heated area experiences a drop in yield strength, as well as an expansion leading to plastic deformation. When cooled down, tensile stresses are induced that can cause crack initiation. The repeated process of heating up the wheel and the following cooling down period can thus lead to cyclical loading as well as residual stresses. [9]

Due to the nature of thermal cracks and RCF, it is not uncommon for these phenomena to occur together in railway wheels. The weakening of the material induced by thermal loading could allow RCF cracks to grow. In an experiment carried out by Kazuyuki Handa et al., thermal cracks only appeared in the region of the wheel with rolling contact, which suggests that rolling contact is necessary for thermal cracks to appear. [12]

2.2.4 Wheel flats

A wheel flat is a local out-of-round wheel defect, which may cause wheel-rail impact loads on each wheel revolution. Wheel flats occur when applied braking force exceeds the available friction on the rail, which causes the wheel to lock and slide along the rail. This wears the wheel tread flat and causes high local temperatures from dissipated frictional energy, which when cooled may lead to material phase changes

and residual stresses. This material change in combination with impact loads can rapidly cause crack formation and further material loss. Aside from damaging the wheel, the high impact loads risk breaking or initiating cracks in the rail. Wheel flats also cause impact noise and worsen ride quality. [17]

Sliding could be caused by vehicle factors like poorly adjusted, frozen, or defective brakes; or friction affecting contaminations on the rail like leaves, snow, frost or grease. Mitigation measures include early detection to perform maintenance before extensive damage is done, proper brake maintenance, vegetation management to avoid slippage from leaf residue, proper friction management like sanding, good vehicle anti-slip systems, or less aggressive braking.

Wheel flats are usually monitored by wheel impact load detectors on the rail, but there are also vehicle-based methods based on measuring axle box accelerations [19]. They can also be detected during visual inspections or when measuring the wheel profile. There are different alert and action levels which are either set by measured impact load, or measured wheel flat length or depth. These vary in different countries and for vehicles of different axle loads. Note that impact load do not necessarily correlate with wheel flat geometry, so it might be better to base regulations on measured impact load [16].

2.3 Bearing failure

Bearings carry the entire load of the vehicle to the rotating axle and wheels, so a failure can lead to catastrophic consequences. Bearings are subject to similar deterioration phenomena as other metal-metal contact systems, like RCF, cracks, wear, and various localized effects. To reduce friction in the bearings, improve heat dissipation, and protect against corrosion, lubrication is used. As time passes, lubricant loses its properties, so it must be reapplied at regular intervals. If a bearing has excessive friction from improper maintenance or a defect, the bearing will produce large amounts of heat which could either seize or eventually melt the bearing if the vehicle is not stopped. Either of these could result in a serious derailment. [1]

Slow phenomena like wear and crack development can be monitored by visual inspection when disassembled or by various non-destructive testing methods. Any defects produce anomalous vibrations and noise, which can be monitored using track-side or vehicle-based acoustic or vibration sensors. Fast phenomena like thermal failure can be monitored by measuring the bearing temperature, either by on-board temperature sensors or track-based hot box detectors, however these only warn after a failure already has occurred. Additionally, track-based hot box detectors are prone to false alarms e.g. if the wheels have been heated from a prior brake application. For a more detailed overview, see [1].

3

Operational conditions

This chapter describes how the operational conditions affect rates of different phenomena, maintenance and inspection possibilities, and what logistical issues occur. There are three major influencing factors for wheel damage: speed, axle load, and temperature (Erik Nygårds, personal communication, 2024-05-14). Higher speeds produce higher dynamic loads, and higher axle loads create higher forces. Low temperatures and winter conditions create all kinds of problems from high friction during cold and dry conditions, lubrication from melting snow in cracks, materials becoming brittle, brakes freezing, and ice freezing on bogies increasing the mass and hence the dynamic loads [7]. A smaller wheel diameter increases contact pressure and the number of load cycles from more axle rotations.

3.1 Long distance and regional passenger trains

Passenger vehicles generally have one or two dedicated workshops for heavy maintenance. If maintenance is scheduled or any defect is discovered, the train needs to do a maintenance run to the depot, which can be quite a long distance depending on the vehicle's operational range. An unplanned depot stop could represent a large amount of lost income, since each missed run would have carried a lot of paying passengers.

The high average speeds and short turnaround of many passenger trains means each vehicle travels a long distance each day. Since maintenance is often distance-based, this means maintenance may need to be performed more often than on other vehicle types. Passenger trains generally travel on fast and well maintained track with larger curve radii, and mainly use disc brakes or regenerative braking. Since short curve radii and tread braking is often avoided, wear rates may be lower than for other vehicle types. However, the lower wear rates may mean initial crack development of RCF does not get worn off, possibly increasing the rates of these phenomena [10]. Not using tread brakes reduces wheel heating, decreasing the risk of thermal cracks.

3.2 Operational conditions of freight wagons

Freight wagons are mostly affected by phenomena caused by heavy loads and tread braking. Long distances and heavy axle loads increase rates of rolling contact fatigue, plain fatigue and regular wear, while heavy tread braking risks thermal cracks and

increased wear rates. Since freight wagons spend almost their entire life unprotected outdoors, corrosion is common.

The operational conditions of freight wagons cause large logistical issues. During route planning, regular monitoring has to be ensured. Wheelset defects that do not allow further regular operation cause large logistical issues since the wagon must immediately be transported to a maintenance centre. In some countries, the transport conditions have to be set by a committee containing various involved actors. The further transport of the goods can also become an issue, especially if a heavily modified or specialized wagon is necessary. This section is based on information provided by Peter Gabúľ at ŽOS Zvolen, a.s. (personal communication, 2024-05-03).

3.3 Operational conditions of trams

Operational conditions of trams are quite different to other rail vehicles. During operation, they have to negotiate much tighter curves, they stop and accelerate more often, and in some cases they steer using the flange instead of the wheel tread. All of these factors affect the rates and types of defects occurring on such vehicles. This section is based on [15] and information supplied by Jiří Vacovksý at Plzeňské městské dopravní podniky (personal communication, 2024-04-17).

One of the most problematic parameters which has to be monitored often is the wheel tread profile. High rates of creepage occur in curves with a small radii, which are necessary to navigate tight streets within the city. This leads to increased wear on the wheels. In addition to the consequences of wheel wear mentioned in section 2.2.1, trams with very worn wheel profiles running on embedded rails could risk moving the contact point from the rail to the road surface. This in combination with debris collected in the flangeway could result in a derailment. Additionally, rough transitions between ballasted and embedded track risk creating dynamic forces that can cause further damage to the wheel.

Wheel flats are another common phenomenon. These can be formed due to slip occurring during hard braking. Their formation is usually related to a faulty anti-lock braking system, malfunctioning motor or the influence of weather, especially with wet or icy conditions or during autumn when leaves fall onto the track.

Monitoring of these vehicles is very frequent. Since trams usually stay in the same depot every night, it is easy to regularly check the status of the wheelset. They also often undergo a more in depth inspection when their wheels and flanges need to be reprofiled approximately once per year. These factors with the possibility of using track side sensors for automated measurements allows the tram provider to have good oversight of the fleet. Implementation of sensors also allows for quick detection and intervention in case of a wheel flat, which can prevent further damage to both the track and the vehicle.

Most of the maintenance is usually carried out in provider's own service center. This means that any repairs can be done rather quickly. Some workshops might not be capable of performing heavy maintenance of the vehicle such as changing the metal tires, meaning the vehicle has to be transported to a specialized service centre.

4

Current practices

In this chapter we will provide an overview of current practices from selected actors from the industry as well as of the general industry structure.

4.1 Industry structure

Rail vehicle operation involves multiple actors with different roles. Note that these actors do not necessarily have to be different companies, for example many formerly nationalized railways like SJ own, operate and maintain its vehicles. These actors and their roles are described as follows:

- The vehicle manufacturer provides maintenance documents containing what maintenance needs to be done, and maintenance intervals (km-based or date based). It is also responsible for specifying which components that are safety critical.
- The vehicle owner is ultimately responsible that the vehicle is properly maintained. Vehicle owners must register vehicles in either national vehicle registries or the European Vehicle Registry (EVR), where the vehicle owner must provide an Entity in Charge of Maintenance (ECM). This is regulated by EU 2018/1614 [6].
- The entity in charge of maintenance (ECM) is an actor that has been certified to actually carry out vehicle maintenance, as regulated by EU 2019/779 [5].
- The vehicle operator is responsible for day-to-day operation. Procurement contracts generally include procurement for maintenance, so the vehicle operator will be responsible for finding a maintainer. For some operations the maintenance can be done in-house, for example commuter trains with their own depots or metro services that aren't connected to the national network. For most other services, the wheelset maintenance is outsourced.
- The actor responsible for light maintenance and heavy maintenance. Some lighter maintenance can be done in regular overnight depots like reprofiling in an underfloor wheel lathe. However, these depots might not have the equipment for heavier maintenance that requires lifting the train, like wheelset replacement or bogie repairs. Therefore it's common for lighter and heavier maintenance to be done by different actors.

This information was helpfully provided by Lars Danielsson at WSP (personal communication, 2024-04-25).

4.2 Wheel manufacturers

Lucchini is a wheel manufacturer and heavy maintainer which in Sweden mainly serves passenger trains. They do heavy maintenance for their customers by replacing wheels and servicing or replacing other components such as bearings, brake discs and gearboxes. The following is based on an interview with Mikael Rahunen at Lucchini Sweden (personal communication, 2024-04-26).

Maintenance is usually based on the travel distance of the components. After set intervals a wheelset is sent for maintenance where the diameter of the wheel is measured and the wheel is inspected for damage. Other components are also inspected like brake discs, bearings and the gearbox. If disassembly of the wheelset is required, which it usually is if it has reached Lucchini, the bearings will be sent for review as required by regulations. New or revised wheels and parts will be fitted, and the wheelset is sent back to the customer. Operators commonly match maintenance times for multiple components since it is cost-efficient to revise as much as possible when a wheelset is disassembled. However, this might lead to parts being swapped out while still having remaining operational life.

There is a challenge in the industry regarding data of damage and incentives for third party workshops. Lucchini has highlighted a need for more specific data regarding the life of the wheel, for example damage types, wear rates, and maintenance records. By studying data from the lifetime of a wheelset, it is possible to see if specific damage types are more common than other, if proper maintenance of the wheel has been carried out, or if certain operational conditions could benefit from certain changes. Based on the data, the manufacturer can recommend a change in material, more frequent maintenance or small changes in operation. An example of this could be if a wheelset has a long time between maintenance. This could lead to crack growth which would require even more material removed from the wheel when it is time for maintenance. A solution to this could be more frequent instances where only a small amount of material is removed, thus removing any cracks that have started to form. Since many crack development phenomena develop exponentially, frequent reprofiling could increase the lifespan of a wheelset.

One problem preventing large changes in the industry is the lack of incentives for any third party contractor that carries out maintenance. Contracts may be formed in a way that a third party workshop charges an extra fee if the wheelset needs to be changed. Thus, by recommending changes which increase the lifespan of a wheelset, the third party workshop would lower its income. Furthermore, a third party might not have the same means of collecting data about wheelsets compared to an operator with in-house maintenance, which would complicate data collection for the manufacturer.

4.3 Maintenance centres

This section takes a closer look at maintenance centres that perform general repairs of wheelsets with a specific focus on inspection methods.

4.3.1 SweMaint AB

SweMaint AB is a Swedish maintenance actor specializing in freight wagons. Their maintenance centre in Gothenburg performs heavy wheelset maintenance and wagon repairs, which we visited. SweMaint own and maintain their own wheel pool which freight wagon owners can lease from, but they also perform maintenance for other actors who own their own wheelsets.

Their wheelset maintenance is as follows. It sets out with a visual inspection for various types of damage like RCF, lipping (plastic deformation), and wear, before manually measuring the wheelset diameter and the wheel profile. The bearings are then taken off for cleaning or replacement. Here they decide if they reprofile or scrap the wheels. The entire wheelset is sandblasted, which makes the following visual inspection of the axle for damage easier. They also do an ultrasonic and x-ray inspection for cracks on the axle and sometimes the wheel. Which non-destructive testing (NDT) method is used varies for different customers and for different maintenance actions. Small-scale damage on the axle is ground off. If any wheel should be scrapped, they take both wheels off the axle in a wheel press and put new ones on. If not scrapped, the wheelset is reprofiled in a wheel lathe (figure 4.1), then painted. Finally, the wheel profile is laser measured (Johan Sjöholm, personal communication 2024-05-06).

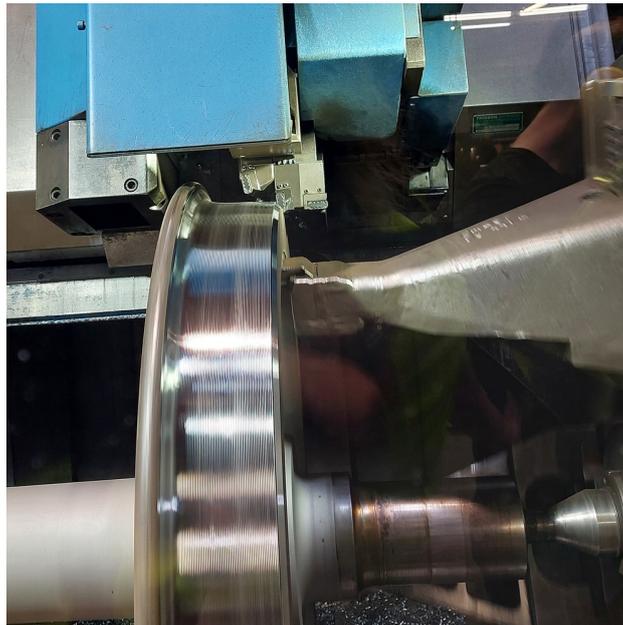


Figure 4.1: Wheel lathe used at SweMaint.

4.3.2 Železničné opravovne a strojárne Zvolen, s.r.o.

Železničné opravovne a strojárne Zvolen, abbreviated to ŽOSZV, offer full services related to operation of locomotives and freight wagons. Their workshop in Zvolen focuses on performing general maintenance of diesel locomotives. This section is based on information provided by Peter Gabúľ at ŽOS Zvolen, a.s. (personal communication, 2024-05-03).

The general maintenance of wheelsets begins with a visual inspection and cleaning of the wheelset. After that, the wheelset is dismantled and non-destructive tests (NDT) can take place. These can be categorised into three groups based on the defect they can discover.

The first group consists of tests that would find defects on the surface of the wheel or axle. Material roll-out, dents, corrosion or wheel flats can be discovered by visual inspection. Magnetic particle inspection (MPI) is used to find surface cracks. This method is based on the magnetic inhomogeneity caused by the crack. The non-homogeneous magnetic field will attract magnetic particles from the magnetic spray or powder, thus revealing the location of the defect. The magnetizing tool used by ŽOSZV is shown in figure 4.2. MPI is commonly combined with an ultraviolet light, which allows for easier detection of the cracks. A crack visible under an ultraviolet light is shown in figure 4.3.



Figure 4.2: Electromagnetizer used by ŽOSZV, made by ATG



Figure 4.3: Crack under ultraviolet light

Another method of discovering surface cracks is using penetrant testing. This method is used for surface crack detection on non-ferromagnetic materials. For more information regarding this method, see [2].

The second group of NDT methods detect subsurface cracks on axles or wheels. The most common method is ultrasonic testing (UT). UT is based on the reflection of the ultrasonic wave after it interferes with a defect in the material. An ultrasonic measuring device, Panametrics EPOCH 4, used by ŽOSZV is shown in figure 4.4.



Figure 4.4: Panametrics EPOCH 4 Ultrasonic Flaw Detector

The last group of NDT methods detect incorrect wheel dimensions. The following parameters are measured using specialized sliding calipers: Wheel diameter and width, axle diameter, height of the wheel rim if it is a tired wheel, flange height and thickness and the distance between the inner sides of the wheels. Based on these calculations further parameters are calculated, for example track gauge and flange steepness. Furthermore, the wheel profile is checked using a profile gauge. After reprofiling and maintenance, all of these parameters must comply with the demands of the customer and legislation before leaving the workshop.

4.4 Train operators

SJ is the largest train operator in Sweden. With a wide fleet of different train types, they operate various routes with different characteristics. Such operations bring the need for clear maintenance routines to detect and prevent wheel damage that could lead to expensive failures. The following is based on information provided by Erik Nygård at SJ (personal communication, 2024-05-14).

It is important to detect and rectify wheel damage before cracks are allowed to grow and cause further problems, which would require heavier maintenance. For this, SJ uses trackside detectors on strategic locations, which can measure wheel damage. In addition, bogies are inspected after 12 500 km, which is around two weeks of operation. The newly renovated X2000 also has sensors on the bearings which can detect abnormal vibrations from wheel damage. If anything out of the ordinary is detected by on board personnel, it is reported and brought to maintenance if necessary.

For the X40 and X55, SJ has started doing in-house maintenance dating a few years back. The governing maintenance philosophy is to frequently re-profile wheels, thus removing less material in total than if maintenance were done sparsely and cracks were allowed to grow, thereby extending the lifetime of a wheelset. In the case of larger damage to wheels, a train usually has to divert from planned operations to head for maintenance as soon as possible. This is usually the case if it is reported by on-board personnel, since the damage has to be quite large for it to be noticeable. Note that if one wheel is damaged, both wheels on the axle might need to be reprofiled to match the wheel diameters. For some models this extends to all wheels on the bogie or even all wheels on the wagon. When wheels are at the end of their lifespan, the train is sent for heavier maintenance to a third party workshop. The vehicle owner is ultimately responsible for the vehicle and thus have the final say in what work is to be done, however a third party workshop can make suggestions for actions to be taken. When the wheels have to be removed, the dismantled bearings also have to be sent for revision as required by regulations. The gearbox and brakes are also inspected and parts are replaced if they show signs of a reduced lifespan. This is to have matching lifespans for all parts in the wheel assembly to make for more predictable operations while also reducing how often a train has to go in for heavy maintenance.

SJ highlights the difficulties of winter conditions with increased rates of deterioration, see chapter 3. The maintenance plans need to account for this, with backup wheelsets on hand and frequent re-profiling of wheels to avoid excessive crack propagation. Enough depot space is needed to thaw frozen brakes and bogies.

The main goal is to increase the lifespan of components and thus the operational hours of a vehicle. Often this means increasing the lifespan of the wheels since other components of the wheelset usually have a longer lifespan. As previously mentioned, this is done by detecting wheel damage as early as possible using various methods, and rectify damage through frequent maintenance and re-profiling. Other options can be explored, such as data sharing between different parties and changes in the usual operation. However, it is important to keep in mind that changes that can increase performance in one area can affect another area negatively, for example changing wheel material might lead to more wear on the rail and thereby higher track access charges.

4.5 Tram operators

In this section, we will take a closer look at the monitoring approaches used by various tram operators.

4.5.1 Plzeňské městské dopravní podniky, a.s.

Plzeňské městské dopravní podniky, abbreviated to PMDP, ensures the majority of public transport services in the territory of Pilsen, Czech Republic. Their tram system consists of 3 lines operated by a total of 104 vehicles. This section is based on information provided by Jiří Vacovský at PMDP (personal communication, 2024-04-17).

When it comes to defects, PMDP's main concerns are wheel flats and regular wear. Main causes for wheel flats are anti-slip system failures or faulty motors. Occurrence of these failures is in the single digits every year. Weather influence is also important, especially in combination with the driving style of the tram operator. There is a higher chance of slip during the wetter months in spring and fall.

Their monitoring approach does not involve any automated measurements. They visually check the wheels every day. Further, during more in-depth inspections, they use one of the 3 following methods. The first method involves using a profile measuring device Miniprof. Another approach uses a laser measuring device. This device is capable of measuring wheel diameter, wheel profile, flange height, thickness and steepness. The last approach consists of measurements of the wheels taken on a underfloor wheel lathe during maintenance.

Due to the size of their fleet, almost all repairs are done by an external contractor. Wheel reprofiling is almost exclusively done using an underfloor wheel lathe. Wheel profile has to be refreshed once per year, unless the wheel has sustained other types of damage. Changing the metal wheel rim happens every 4–5 years and is done during heavy maintenance.

4.5.2 Dopravní podnik hl. m. Prahy, a.s.

Dopravní podnik hl. m. Prahy, abbreviated to DPP, ensures the majority of public transport services in the city of Prague, Czech Republic. Their tram system consists of 35 lines operated by a total of 766 vehicles. This section is based on information provided by David Hladík at DPP (personal communication, 2024-04-17).

For now, their monitoring approach does not involve any automated measurements. Wheels are checked visually for mechanical damage during pre-service treatment every day. Wheel profiles and dimensions are checked approximately every 12 000 kilometers manually. The exact interval differs for each tram type. Wheel profiles are measured using a profile measuring device Miniprof and wheel dimensions using sliding calipers. Axles are checked during regular maintenance of the vehicle every 120 000–220 000 kilometers depending on the specific tram model. During the regular maintenance, wheel back to back distance is also checked using a sliding caliper. Their newest tram model, the Škoda 15T has independently rotating wheels, thus does not have an axle, but rather an axle bridge. These are inspected during scheduled maintenance approximately every 660 000 kilometers.

Measurements of flange height, thickness and wheel diameters are uploaded to a vehicle database software, where the development is monitored. The limit values and tolerances vary for each tram type and are given by the tram manufacturer, legislation or internal regulations.

DPP also plans on implementing laser-based measuring stations in 3 of their depots. These stations will be fully automated and capable of measuring wheel profile, diameter and wheelset gauge.

4.5.3 Dopravný podnik Bratislava, a.s.

Dopravný podnik Bratislava, abbreviated to DPB, ensures the majority of public transport in the city of Bratislava, Slovakia. Their tram system consists of 5 lines operated by 204 vehicles. This section is based on information provided by Juraj Mesík at DPB (personal communication, 2024-05-09).

DPB operates mainly two types of trams; the older ones are made by ČKD-Tatra equipped with monoblock wheels and newer models are Škoda 29T and 30T with ringed wheels. The lifespan of wheels is approximately 500 000 km on the old trams and the rings last 600 000 km on the newer models. Although the wheels on the older trams are monoblock from the factory, DPB is able to modify the wheels to create tyred wheels to save costs. The lifespan of these modified wheels is similar to the original monoblock wheels. DPB is capable of changing the metal wheel rim themselves. Turning the bogie around, so the leading axle will become the trailing axle also helps to extend the lifespan of their wheels.

Majority of maintenance is done in their own workshop. Slight profile adjustments are done using an underfloor wheel lathe. Larger reprofiling takes place in an above floor wheel lathe during heavy maintenance. DPB utilizes an "economical" profile, which does not restore the wheel to the original state, but instead makes the flange thinner to save material, thus extending the lifespan of the wheel.

When it comes to monitoring, DPB uses automated measurements. These take place every day, before the tram enters the depot. Diagnostic station KOLTECH PZK2, shown in figure 4.5, is capable of measuring the wheel profile, wheel diameter, track gauge and wheel back to back distance. All these measurements are sent to a database, where their development is monitored. Alert limits are set for wheel thickness, diameter and back to back distance. When alert values are measured multiple times, the vehicle is scheduled for maintenance. Further measurements are taken during scheduled maintenance, however other NDT methods only take place after repairs have been done to the wheels.



Figure 4.5: Diagnostic station KOLTECH PZK2 taking measurements

5

Discussion and conclusions

In this chapter, we will discuss important factors that need to be accounted for when developing a suitable business plan for wheelset monitoring and maintenance. A few connections between possible approaches and fleet parameters have been noted, for example size of the fleet or operating range. There is also a possibility to rent a wheelset on subscription base.

5.1 Monitoring

Monitoring is a key part when it comes to optimizing the lifespan of a wheelset. Discovering the damage as early as possible allows for quicker intervention, which in turn prevents damage to other components. However, the monitoring intervals need to be set correctly so that human resources are not wasted and possible revenue from the vehicle is not lost due to it being out of operation. A possible solution can be the implementation of automated measurements, however they have their limitations.

5.1.1 Automated measurements during operation

There are two possible methods when it comes to automated measurements. Track-side measurements utilize sensors placed along the track. When it comes to long distance travel, it is useful to gather data from such sensors since they provide a better overview of vehicles that otherwise would be inaccessible, for example freight wagons. These sensors are often owned by the track owner, so there needs to be a contract formed between involved actors. If the fleet operates in a smaller area or has a depot where every vehicle often goes to, it is useful to have an automated measuring station installed there that takes measurements of wheel parameters. This enables a better understanding of the development of wheel health.

Sensors implemented on the vehicle are also a great tool to gather data on the wheelset health. Since data collection became the standard in recent years, newer vehicles can be equipped with such sensors. However, retrofitting them onto older vehicles might not be beneficial depending on the remaining service life.

The measurements from these sensors are not always 100% accurate. There are many external factors influencing the measurement which need to be taken into account when analysing the gathered data, for example dirt accumulated on the wheels.

5.1.2 Inspections during maintenance visits

Manual inspections are a necessary part of the monitoring process. In many cases, they allow for precise measurements in a controlled environment with high repeatability. However, there are always uncertainties due to human factors. These are usually carried out during scheduled maintenance, and the depth of the inspection is dependent on the maintenance itself. When a vehicle is stationary or dismantled it is beneficial to check as many parameters as possible.

5.2 Maintenance

When structuring the maintenance plan for a fleet, an operator should consider its fleet size and uniformity of the fleet. Disregarding external factors, in-house maintenance could be preferred since the operator has full control of the maintenance. Data sharing is easier and the operator has more control of the condition of the fleet. There is also no external part that may want to oversize the maintenance. However, in-house maintenance may not always be suitable. The total size of a fleet will determine if its profitable to have in-house maintenance. If a workshop does not have any vehicles to work on, it is inefficient and loses money. A fleet with multiple vehicle types may require different maintenance routines and thus different workshops to have efficient maintenance. The suitability of in-house workshops is also affected by the extent of maintenance, since heavier maintenance may require completely different equipment and routines.

Looking at the lighter maintenance of the wheels, there is a common conception from multiple actors that frequent reprofiling of the wheels is preferred over sparse maintenance that requires more material to be removed. This prevents cracks to grow beyond an initial phase and leads to an increased lifespan. Different methods of detecting wheel damage are used to monitor the wheels to allow for better maintenance planning.

Regarding heavy maintenance, multiple actors stated that they want to sync maintenance intervals for different components. For example: if the wheel lasts 800 000 km and the bearing lasts 1 000 000 km, the bearing still needs to be refurbished when removing the wheel, wasting 200 000 km of useful life on the bearing. If the lifetime of the wheel could be increased to 1 000 000 km so lifetimes match, money could be saved on fewer bearing refurbishments. This extends to all components that can only be maintained after the wheel is taken off, like gear boxes and brake discs.

5.3 Interaction between actors

Many of the interviewed actors stated that cooperation and communication between actors is important for both monitoring and maintenance. Train drivers and onboard staff can notice when acute maintenance is needed, and depot staff have great knowledge of the health of the vehicle. The infrastructure owner has track-side detectors and can warn about excessive rail damage. The bearing manufacturer and main-

tainer knows about bearing phenomena, and the wheel and vehicle manufacturer has knowledge about design. There are many opportunities to decrease costs and increase wheel life if all these actors cooperate and share their specific knowledge.

However, this introduces a new challenge which is data handling. Since a given value can be measured using many different methods that have individual biases, and stored with different precision, standardization becomes an issue. This also complicates traceability. Data handling and security is expensive, especially if multiple actors are involved. Furthermore, there is not always an incentive for an actor to share data. A party might be hesitant to share data in order to prevent it from reaching a potential competitor, who can acquire an advantage from it.

5.4 Final remarks

All phenomena occur in parallel, in different proportions, while interacting with one another. This makes identifying precise phenomena much less interesting or relevant for maintenance actors compared to the end result of how long a wheel lasts. However, if one phenomena starts dominating, it can be a sign that something is wrong. Additionally, a deeper understanding of all phenomena can result in an increased wheel life by informing change of the wheel material, vehicle design, or by improving monitoring and maintenance procedures.

Possible business plans within wheelset maintenance vary for different actors. Monitoring and maintenance procedures are well known and quite standardized throughout the industry. Instead, the issue is making sure everyone makes money from a contract. There is a lot of variety within wheelset maintenance, for example in-house or third party maintenance, or a shared wheel pool. Large operators with their own depots have very different needs from small operators that may not even own a single locomotive. Freight wagons have different maintenance needs than long distance passenger trains or trams. Therefore, business plans should be customized to match the operational conditions of the vehicles and needs of the involved actors.

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Dopravný podnik Bratislava, a.s. is the main public transport provider in the city of Bratislava, Slovakia. It operates all of the tram and trolleybus lines and also majority of bus lines within the city. The company is 100% owned by the city of Bratislava. A major priority of DPB is providing an eco-friendly public transport solution. We thank Juraj Mesík for his time and consideration. Visit www.dpb.sk for more information.



Železničné opravovne a strojárne Zvolen, a.s. is the biggest and most significant company with focus on maintenance and modernization of diesel locomotives and diesel multiple units vehicles (DMU) in Slovakia and Czech Republic. Rolling stock repair has more than 150 years of tradition since the establishment of railway workshops in Zvolen in 1872, the predecessor of today's ŽOS Zvolen, a.s.

The company provides repairs for a wide range of bogies, diesel locomotives, DMUs, and passenger cars, all while meeting the specific requests of its customers. Nowadays, ŽOS Zvolen, a.s. aims to expand its business internationally in the following fields:

- Modernization and remotorizing of diesel locomotives and multiple units
- Repairs of railway vehicles and their aggregates
- Regular examinations set by the V25 regulation
- Repairs of electric locomotives 140, 181, 182 and 183
- Electrical revisions and revision of the pressure tanks of railway vehicles
- Repairs of railway vehicle components

We thank Peter Gabúľ for his time and consideration. Visit www.zoszv.sk/sekcia-en-25-introduction for more information.



SweMaint AB is the biggest maintenance actor in northern Europe for freight wagons. They have workshops in various places all around Sweden where they perform maintenance on wheelsets and wagons, both preventative and acute. We thank Johan Sjöholm for his time and consideration. See www.swemaint.se for more information.



SJ AB is a Swedish state owned train operator and owner that runs most long distance services in Sweden on a market basis. Additionally, they also run some procured regional services, and have some in-house maintenance and other supporting functions. We thank Erik Nygårds for his time and consideration. Visit www.sj.se/om-sj for more information.



Dopravní podnik hlavního města Prahy

Dopravní podnik hl. m. Prahy, a.s. is not only the most important carrier within the Prague Integrated Transport system (PID), but also the largest in the Czech Republic. It operates on all metro lines, trams, trolleybuses, most urban and several suburban bus lines and the cable car to Petřín and the Prague ZOO. The company is 100% owned by the Municipality of the Capital City of Prague. The transport company builds on a rich experience with more than 120 years of tradition of its predecessors and has transformed through gradual development to its present form. Today, the public transport system in Prague is among the European and world leaders and has become a model for other public transport systems. We thank David Hladík for his time and consideration. Visit www.dpp.cz/en for more information.

Plzeňské městské dopravní podniky



Plzeňské městské dopravní podniky, a.s. is the operator of urban public transport in the city of Pilsen, Czech Republic and its surroundings. The company's tradition dates back to 1899, when their electric tram first started running in Pilsen. Today, 125 years later, trams, along with trolleybuses and buses transport more than 100 million passengers annually. An important feature of Pilsen's urban transport is its environmental friendliness: two thirds of the transport capacity is provided by tram and trolleybus transport, i.e. modern means of e-mobility. Buses provide transport mainly on the periphery of the city. We thank Jiří Vacovský for his time and consideration. Visit <https://en.pmdp.cz> for more information.



WSP Sverige AB is a consultancy company with a large presence in the railway sector, from development of new lines and service procurement to asset management and contract issues. We thank Lars Danielsson for his time and consideration. Visit www.wsp.com for more information.



Lucchini Sweden AB is a heavy maintainer and wheelset manufacturer, mainly for passenger wagons. They perform maintenance on wheelsets, gearboxes and bogies. We thank Mikael Rahunen for his time and consideration. Visit www.lucchini.se/company/about-us for more information.

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