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Maintenance Performance Improvement for Rolling Stock Wheels

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The service life of a railway wagon wheel can be significantly reduced through failure or damage, leading to excessive costs and accelerated deterioration. In order to monitor the performance of wheels on heavy haul wagons, this paper proposes implementing the Plan, Do, Study, and Act (PDSA) maintenance performance improvement process. As a case study, it looks at wheels on the heavy haul wagons of a Swedish company, considering all factors that may influence the need for maintenance. After investigating the PDSA process, it proposes the use of Key Performance Indicators (KPIs) for both risk and economic reasons. The paper concludes that the PDSA process and KPIs are useful tools to improve the maintenance performance of railway wheels.

1. Introduction

Railways capitalize on the low resistance between wheel and rail to create an energy efficient mode of transport. However, increasing emphasis on maintenance and life cycle costs (LCC) for rolling stock, such as wheels, and for infrastructure results in the need to predict wheel and rail wear (Enblom and Berg, 2005) to optimize maintenance decisions and estimations of remaining useful life. One of the most important elements in the dynamics of a railway vehicle is the interaction between the wheel and the rail (Charles et al., 2008). The wheel profile determines the stability of a vehicle (Barke and Chiu, 2005), and the rate of wheel surface wear determines the life length of a wheel (Braghin et al., 2006). Thus, effective maintenance will increase the wheel's life. But maintenance of rolling stock not only increases the life of the stock; it also reduces rail degradation (Kumar et al., 2008). As the wheels are in direct contact with the rails, degradation on the wheel surface and profile will cause rail degradation. Reduced wheel degradation through proper maintenance will therefore result in less rail degradation.

The most common wheel problem is flange wear (Larsson et al., 2003), a consequence of friction between wheel and rail (Reddy et al., 2004). To restore the flange, a substantial amount of metal is removed from the wheel tread. The four wheels of a bogie wear differently, depending on their position within the bogie, indicating differences in wheel/rail forces (Palo et al., 2012b).

To evaluate the condition of the wheels, condition monitoring equipment is placed along the track, using a technique called wayside detection. Either wheel/rail forces or wheel profiles can be measured to monitor the condition of wheels. Another method of monitoring is visual inspection of the wheels at the railway yard. Wheel monitoring is also performed in the wagon workshop when the wagon is there for repairs or regularly scheduled maintenance.

The life cycle cost (LCC) of a product can be considered a Key Performance Indicator (KPI) when determining the appropriate maintenance procedure for that product. LCC is made up of the costs to the manufacturer, user, and society (Asiedu and Gu, 1998). It is one of the most effective cost approaches when buying assets for the long term (Jun and Kim, 2007), as it helps engineers justify the selection of equipment based on the total cost over the life of the asset rather than just the initial purchase cost. Even though operating and support costs represent the most significant portion of the LCC, they are the most difficult to predict (Asiedu and Gu, 1998).

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Given the number of stakeholders in the Swedish railway, such as contractors, transparent information systems are critical. The contractors have complete responsibility for all aspects of maintenance and maintenance support; they must guarantee performance and availability. A clear definition of maintenance, including objectives and responsibilities, is very important for cost effective maintenance and problem-free operation (Palo et al., 2012a). In practice, both on-site maintenance engineers and maintenance managers should know how maintenance is carried out and be aware of plans for future improvement (Lin et al., 2011).

This paper only considers wheels; for one thing, studying the whole wagon is very complex, and for another, the interface between wheel and rail has the greatest influence on maintenance costs for the train-track system. Finally, wheels constitute a large part of a railway's rolling stock maintenance cost and a there can be improvement made. The paper is organized as follows. The introductory section gives an overview of the wheel maintenance problem. Section 2 describes the research background and the maintenance process currently used. Section 3 suggests PDSA as a framework for improving maintenance. Section 4 posits LCC as a KPI for maintenance. Section 5 relates the topics under discussion to the case study, while Section 6 presents conclusions and suggests future work.

2. Background

2.1 Iron ore transport

The only existing heavy haul line in Europe, is the Iron Ore Line (Malmbanan); it stretches 500 km from Luleå in Sweden to Narvik in Norway, see Figure 1. The mixed traffic of the line includes both passenger and freight trains. The iron-ore freight trains consist of two IORE locomotives accompanied by 68 wagons with a maximum length of 750 metres and a total train weight of 8 500 metric tonnes, see Figure 1. The wagons are equipped with three-piece bogies, so called because each comprises one bolster and two side frames (Palo and Schunnesson, 2012). These pieces are connected using friction wedges and spring suspensions. The wagons are subject to a kilometre-based maintenance strategy.

In 2011, the LKAB mining company transported 25.7 MGT (million gross tonnes) from its mines in Kiruna and Malmberget; of these, 5.7 MGT were shipped from Luleå harbour. The trains operate in harsh conditions, including snow in the winter and extreme temperatures ranging from -40 °C to +25 °C.

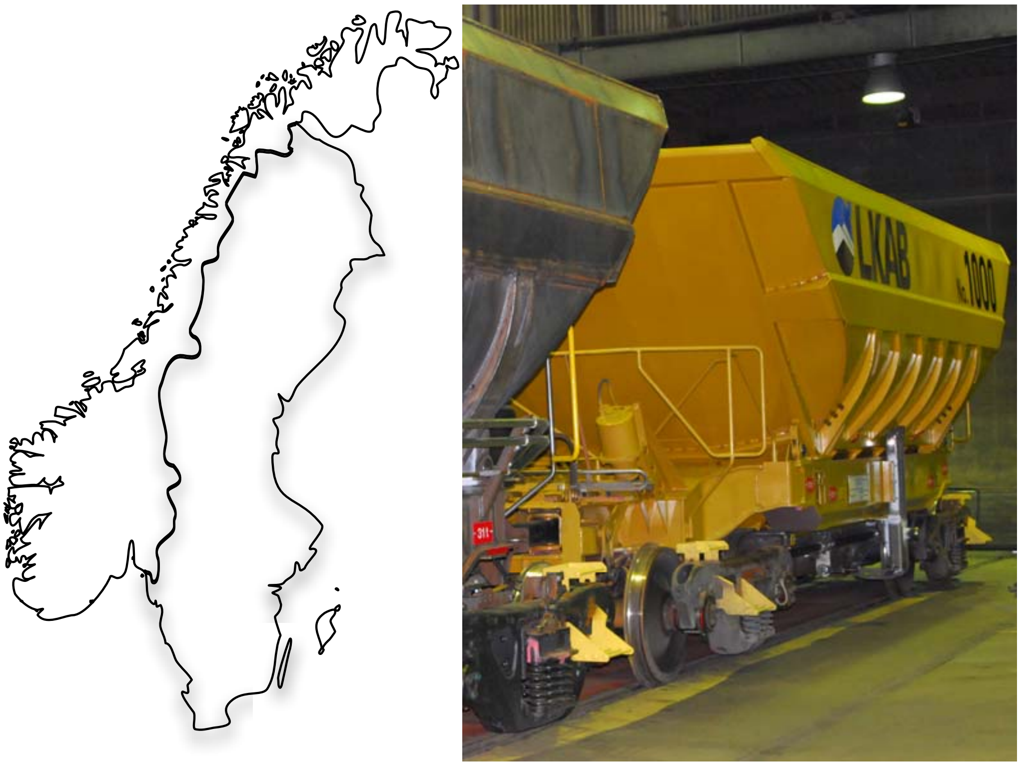

Figure 1: Geographical location in Northern Sweden and an iron ore train

2.2 Maintenance process

There are several methods to detect and monitor wheel wear and wheel fatigue. One is visual inspection of the wheels at the railway yard. Another is the use of wayside monitoring stations to detect faults or failures. A third option is during general wagon maintenance in the workshop. Wheel maintenance decision criteria are stricter and more rigid at the wagon workshop than at the railway yard. If a wagon with bad wheels is at the workshop, the wheels can be maintained before they reach their maintenance limit (opportunity based maintenance actions) (Palo et al., 2012a). There are a number of failure parameters that determine the proper maintenance action for the wheel before it is put back into service.

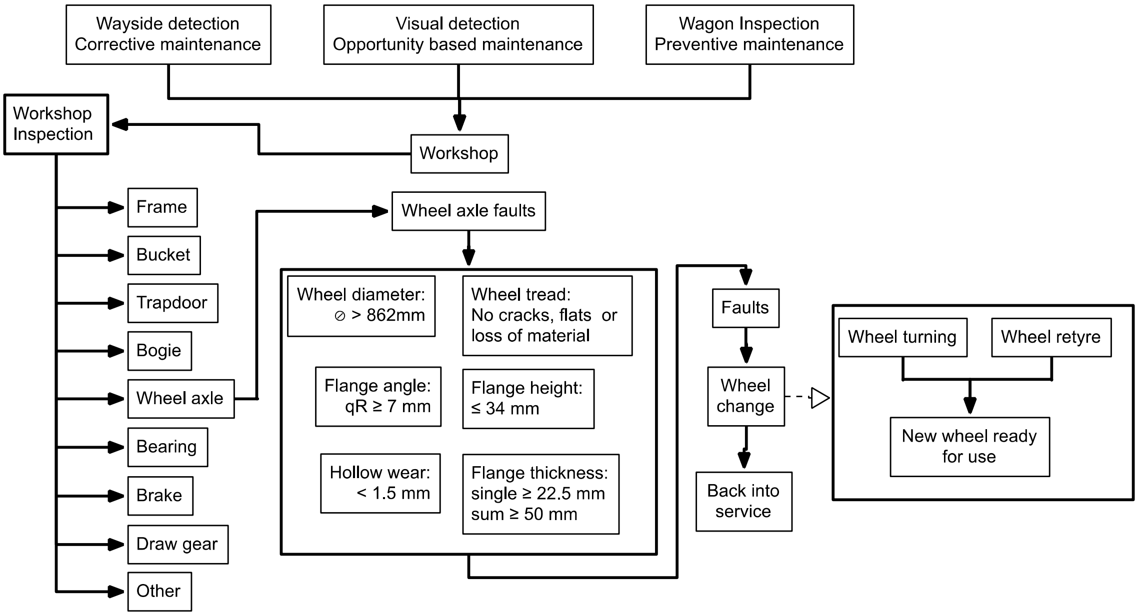

Figure 2: Inspection and maintenance process

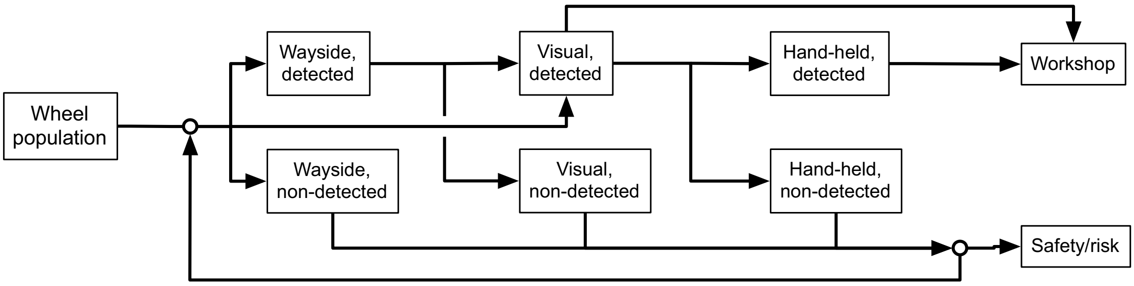

Figure 3: Wheel detection process

Figure 2 shows the overall maintenance process. The work order for a wagon to appear at the workshop can come from three different sources: safety alarms, visual inspections or predetermined running distance. Figure 3 looks specifically at wheels, illustrating what happens to a wheel with a damage or geometry failure at the beginning of the maintenance process. A faulty wheel is detected either visually using wayside detection systems, or manually using hand-held monitoring equipment. From here, a work order is generated and the wheel goes to the next stage. In either of these stages, the wheel can have a fault that is not detected. These non-detected faults represent a certain safety or risk cost.

The risk/safety factor or cost shown in Figure 3 refers to when a wheel has a fault that is not detected; in this case, the wheel will run to failure before it is caught in another detection cycle. The cost associated with these unplanned maintenance actions is treated as a risk cost in this paper. Risk management is a useful tool in decision making and strategy planning.

3. Maintenance performance improvement process

Dr. W.E. Deming developed a plan for continuous improvement, which he called the Shewhart Cycle for Learning and Improvement (Moen and Norman, 2010). The plan has four stages: Plan, Do, Study and Act. This process includes the following stages: plan a change aimed at improvement, carry out the change, examine the results and, finally, adopt the change or abandon it and run through the cycle again (Moen and Norman, 2010). In Figure 4 the maintenance process described in Figure 2 is set into a PDSA cycle.

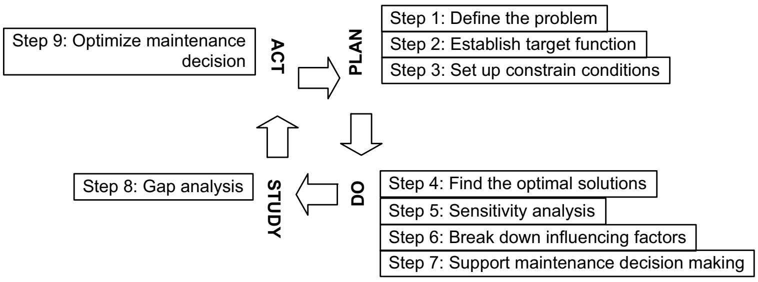

Figure 4: The different stages for continuous improvement

The different steps correspond to different actions taken during the improvement process. The four stages and nine steps are explained in more detail.

3.1 Plan stage

Our aim in the plan stage is to define the problem and set up target functions and constraint conditions. First, we define our area of study, in this case, the maintenance of railway wagon wheels. In our second step, we define the life length of a wheel between re-tyres as 850,000 km of running distance. Next, we determine the number of wagons to be studied. We also determine the various costs: inspection cost, wheel turning (in house or outsourced), wheel re-tyre cost etc. In our final step, we must find and understand the influencing factors and their constraints.

3.2 Do stage

In the execution or do stage, our purpose is to analyze the defined problem. To this end, we first look for the optimal solution, using operations research, non-linear programming, dynamic programming and/or decision theory. Next, we perform a sensitivity analysis of the optimal solution. In the following step, we decide on the influencing factors priorities, for example, the condition monitoring parameters. Finally, we incorporate the influencing factors into the maintenance decision making.

3.3 Study stage

In this stage, our aim is to perform gap analysis on a number of aspects to determine if the changes are leading to improvements. Interesting parameters to consider are the reliability of wheels, maintenance tasks and other key performance indicators (KPIs), as for example, LCC. When studying wheel reliability, we must consider the various failure modes a wheel can have, for example, wheel flats, rolling contact fatigue or profile wear. All these failure modes can have a considerable effect on the degradation of the infrastructure. It is of interest to determine whether there are any gaps between performed and expected maintenance tasks. It is also interesting to investigate whether the working process seen in Figure 2 is optimal. When calculating the LCC, we differentiate the costs associated with corrective and preventive maintenance and summarize the number of times each type of maintenance is performed.

3.4 Act stage

Following the study stage, we review all actions to determine whether maintenance decisions have been optimal and should be continued. Usually, only condition monitoring and failure data are recorded. These data are seldom analyzed with a view to optimizing maintenance strategies, but they are actually very important in reducing unplanned work-orders and optimizing maintenance strategies. Nor should human factors be neglected, as they can have a large influence on the performed maintenance.

3.5 Continuous improvement

As soon as the last stage is completed, the continuous improvement that PDSA is known for can only occur if the cycle is restarted. We must again define the problem and work our way through the whole PDSA cycle.

4. Maintenance Life Cycle Cost Analysis

Reddy et al. (2004) shows how costs associated with rail maintenance are estimated separately for low rail, high rail and curve radius and added up to obtain the total cost of maintenance. The total cost of maintaining a segment of rail is equal to the sum of the following costs: preventive rail grinding cost, down time cost due to rail grinding, inspection cost, risk cost of rectification based on inspection, rail breaks and derailment, and replacement cost of worn-out unreliable rails.

Life cycle cost modeling is highly dependent on the scope and objectives of a model (Jun and Kim, 2007). Operational requirements and maintenance strategies should be developed before developing a life cycle cost model. Life cycle costing is an iterative way to find the most desirable alternatives. A baseline system, which is an initial design concept, may be improved throughout iterative LCC analysis. LCC analysis is a good tool to use as the economic parameter in the PDSA, since it accounts for all costs of a wheel between two re-tyres.

For a railway wagon wheel, the total cost for maintenance can be estimated by adding up the following; Acquisition cost C_A, Inspection cost C_I, Preventive maintenance cost C_{PM}, Corrective maintenance cost C_{CM}, and Risk/safety cost C_R. The LCC is then given by:

$$LCC = C_A + C_I + C_{PM} + C_{CM} + C_R \quad (1)$$

where C_A is the cost of purchasing and installation of two new wheel rims/discs on an axle. This is done either when taking a new axle into service or when the old axle is too worn. Inspection cost, C_I, is the cost associated with inspections and condition monitoring equipment in wayside stations, seen in Figure 3 or the start of the process in Figure 2. This is a fixed cost for each wheel, since it is difficult to predict how often a wheel is inspected or passes a monitoring station. C_{PM} is the cost associated with wheel axle faults, see parameters in Figure 2, detected at either wagon inspections in the workshop or visually when walking by the vehicle in the train yard. C_{CM} is a much larger cost than for preventive maintenance, since it constitutes the additional cost of changing an axle out on the line as well as transporting the vehicle back to a workshop or train yard. C_R is the risk/safety cost in Figure 3, which is calculated from the probability of a stopped wagon on the line.

5. Discussion

The railway makes extensive use of fault detection and condition monitoring tools. By using the data from these systems, an infrastructure manager or train operator can find failures among assets before they reach the point of becoming a fault. In the maintenance process used in our case, data from a number of sources can create a work-order in the workshop. If we refine the thresholds for these monitoring sources, we can optimise the overall maintenance cost.

This paper seeks to find a framework for this optimisation process, using PDSA as a tool. Within this, we have used LCC as the economic parameter, with the cost of risk/safety of wheel failure an important part of this parameter.

The condition monitoring tools available for predicting maintenance needs are not yet used to their full potential. However, accurate predictions can increase wheel reliability and life length and decrease the cost of maintenance.

6. Conclusions

We think this paper offers a good framework to start the process of improving maintenance performance and decreasing the overall cost of wheel maintenance. This is, of course, only a beginning: the framework must be implemented and its performance evaluated before its full scale implementation. The authors are currently working on this; their results will be published in the near future.

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