Evaluation of Track Geometry Maintenance (Tamping) in Swedish Heavy Haul Railroad - A Case Study

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Abstract

Applying the efficient and optimal tamping strategy helps reduce maintenance costs, making operations more cost effective and leading to increased safety and passenger comfort. In this paper, track geometry data from the iron ore line (Malmbanan) in northern Sweden, which handles both passenger and freight trains, are used to calculate track quality degradation trend in a cold climate. The paper describes Trafikverket's (Swedish Transport Administration) tamping strategy and evaluates its effectiveness in measuring, reporting, and improving track quality. Finally, it discusses the lack of data accuracy and notes the various factors involved in maintenance decisions.

Index Terms: track geometry, maintenance, tamping

1. Introduction:

Today's railway industry handles more and faster trains and deals with higher axle loads, but this increased usage can result in faster degradation of railway assets and higher maintenance costs. To assure track safety and maintain high quality standards, we need to devise an optimized and cost-effective track maintenance strategy based on technical and/or safety limits that meet cost-effective maintenance thresholds.

Track geometry maintenance (tamping) is a maintenance action used to compact ballast and correct track geometry faults such as incorrect alignment (lateral deviation) or incorrect longitudinal level (vertical deviation). In Sweden, the annual tamping cost is about 100-120 MSEK, and the total amount of tamped track is approximately 1700 km, about 14% of the total track length [1].

Some researchers have developed empirical models of track geometry degradation with a view to better understanding the degradation [2, 3, 4, etc.]. Others have examined how different variables such as speed and axle load affect track deterioration [5, 6, 7, etc.]. However, a number of researchers claim that current standards and assessment methods may not be adequate for track maintenance, as these do not consider dynamic responses at the wheel-rail interface [8, 9, etc.].

In this paper, we describe the Swedish Transport Administration (Trafikverket) strategy for tamping, evaluate its efficiency and discuss about the quality and accuracy of data. To this end, we use track geometry data from a section of the iron ore line (Malmbanan) between Boden and Gällivare in northern Sweden. We find that time utilization in tamping is not very effective [1], with only about 25% of the available time being used for maintenance execution. The main reason for this low efficiency is limited access time to the track. This review reveals a need to optimize the track geometry maintenance strategy. Briefly stated, an estimation of track degradation and its consequences is required to optimize track maintenance [10]. With this knowledge, we can estimate the right time for inspection, maintenance and renewal.

2. Case study background:

On the “iron ore line”, the Swedish mining company LKAB transports iron ore pellets from its mine in Kiruna to Narvik and from its mine in Vitåfors, near Malmberget, to Luleå. In 2000, LKAB increased the axle load on Malmbanan from 25 to 30 tonnes and the maximum speed of the loaded train from 50 to 60 km/h. This change is likely to result in higher track geometry degradation. In addition to iron ore transportation, the line is used by passenger trains and other freight trains. The train speeds vary from 50-60 km/h for loaded iron ore trains, to 60-70 km/h for unloaded ones and 80-135 km/h for passenger trains.

The annual passing tonnage on the track is about 13.8 MGT. The track consists of UIC 60 rails and concrete sleepers. The ballast type is M1 (Crushed Granite), and the track gauge is 1435 mm. The region is subject to harsh climate conditions: snow and extreme temperatures, ranging from -40˚C in winter to +25˚C in summer [11].

3. Track quality monitoring and maintenance:

To monitor track quality, Trafikverket regularly (every 1-2 months from April to October) uses an inspection car to measure the deviation of the track with an inertia measurement system and an optical system. An accelerometer measures the acceleration of the vehicle; based on the recorded accelerations, the vertical and lateral deviation of the track is calculated for consecutive 25-centimeter intervals.

Based on these 25-centimeter interval measurements, the standard deviation, σ_S, of the monitored cant error (C) and the average monitored lateral position error of the high rail (S_{High}) (see figure 1 and Eq. [1]) are calculated for 200-meter sections. The standard deviation of the average monitored vertical error for the left and right rail, σ_H, is also calculated for 200-meter sections.

$$\sigma_S = \sigma\left[C + S_{High}\right] \qquad \text{[Eq.1]}$$

The standard deviations for lateral and vertical errors (σ_S and σ_H) are calculated from short wavelength signals. Since the recorded signals from the measuring car are the combination of long and short wavelengths, filtering is required. This can be done by selecting only signals in the range of 1 to 25 meters.

Trafikverket uses several condition indices to describe the condition of the track, the most important of which are the Q-value and K-value. These are calculated based on the standard deviation of the vertical and lateral displacements, σ_H and σ_S, and the comfort limits that define the acceptable standard deviation of the longitudinal level for 200-meter track sections (see table 1).

The formula for calculating the Q-value is:

$$Q = 150 - 100\left[\frac{\sigma_H}{\sigma_{H\lim}} + 2\frac{\sigma_S}{\sigma_{S\lim}}\right] /3 \qquad \text{[Eq.2]}$$

Where:

$\sigma_{S\ lim=}$ The comfort limit for the σ_S value, defined for different track classes (see table 1).
$\sigma_{H\ lim=}$ The comfort limit for the σ_H value, defined for different track classes (see table 1).

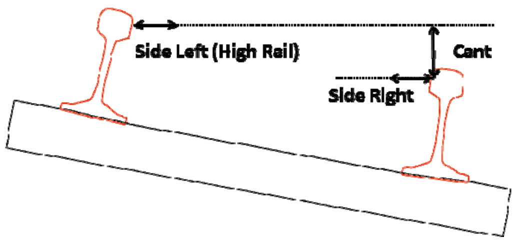


Figure 1: Calculation of σ_S

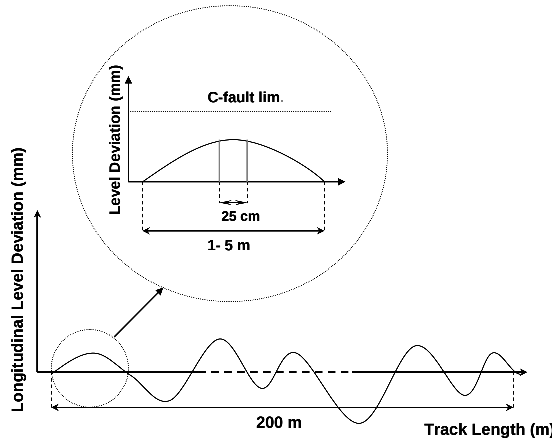


Figure 2: Illustration of C-fault limits

The other index, the K-value, is the ratio between (∑l), the total length of the track with standard deviations below the comfort limits, and the total length of track (L). This index is used to obtain an overall picture of the track condition over a long distance and is calculated by the equation:

$$K = \frac{\sum l}{L} \times 100\% \qquad \text{[Eq.3]}$$

In addition to the Q-value and the K-value, two fault limits are defined for 25-cm track sections, "B-faults" and "C-faults". C-faults, which are safety-related limits, identify the maximum allowable deviation from the design position (see figure 2), while B-faults identify the limits for the execution of preventive maintenance [12]. Although these limits are defined for "point failure" (25 cm), the fault normally occurs over a length of at least 1 to 5 meters due to rail stiffness.

The track of the iron ore line consists of two quality classes, K2 and K3, each with a different allowable speed, dissimilar fault thresholds and comfort limits for local trains (see table 1).

Table 1: comparison of the allowable limits between K2 and K3 [13]

Quality class	Maximum allowable speed for local trains	Comfort limits		B-fault limits	C-fault limits
		$\sigma_{H\ limit}$ Standard deviation of vertical position	$\sigma_{S\ limit}$ Standard deviation of the sum of vertical and lateral position	Maintenance Limit for vertical deviation for 25 cm interval (1-25m wavelength)	Maximum allowable vertical deviation for 25 cm interval (1-25m wavelength)
	Km/h	mm	mm	mm	mm
K2	105 - 120	1.5	1,9	7	12
K3	75 - 100	1.9	2,4	10	16

Trafikverket outsources the tamping of each line to different contractors, mostly using performance contracts. In this type of outsourcing, it is up to contractors to select appropriate methods and plan for the work. They are responsible for both regular measurements of track geometry and tamping, and they base their execution of tamping on the calculated Q-values and C-fault limits.

Tamping is executed as either preventive maintenance or corrective maintenance. Execution of tamping due to the C-fault is considered corrective maintenance; tamping due to the Q value is considered preventive maintenance. This means that if the Q value of the track section falls below the contractual limit and/or there is deviation in the track greater than the C-fault limits (safety limits), tamping should be performed. Tamping is obligatory (i.e., required by regulation) if the C-fault value exceeds the C-fault limit.

In the performance contracts, two limits are specified for the Q value, a goal limit and a contractual limit. If the actual Q value of the track is higher than the goal limit, contractors will receive a bonus, while if it is below the contractual limit, they must pay a penalty.

4. Methodology:

4.1. Data collection and data treatment

Track section 118, between Boden and Gällivare, was selected for the case study. To ensure comparable data, we considered tangent segments of 200 m from quality class K2 and left out other parts of the track, such as curves and stations.

The tamping information for the selected track section was extracted from two Trafikverket databases, BIS (track information system) and OPTRAM. BIS contains information on Trafikverket's infrastructure and facilities, agreements, the history of tamping (such as location of tamped section, length of tamping, date, etc.) and grinding and curves [14]. OPTRAM is a system implemented since 2007 by Trafikverket to show graphically the results of track position measurements. The system provides functionality for analysis and displays data trends [15]. To gain access to all information on tamping, however, it is essential to consider both systems [1].

In BIS, tamping information can be inaccurate, as corrective tamping is not always reported to the system by the contractors because it is not a contract requirement [1]. OPTRAM, which is based on inspection data, is more reliable; however, the data in this system have only been available since 2007. Therefore, a full overview of the long-term degradation of the track could not be obtained for this study.

The standard deviations for the longitudinal level before and after execution of tamping were selected from OPTRAM database, for the period 2007-2009. To evaluate the performed tamping efficiency, we used the tamping intervention graph developed by the Austrian railway (see reference [16]). Here, the tamping efficiency is classified as bad, good or excellent. In the original graph, the maximum value before tamping is 3 mm, and since some data in this case study are greater than 3 mm, the graph has been extended using trend regression analysis (see figure 5).

When the longitudinal level value goes beyond the Intervention Limit, corrective maintenance should be performed. This Intervention Limit (IL) can be defined either for isolated defects or for a 200-m track segment. Trafikverket only defines IL for isolated defects. When the studied data belong to 200-m track segments, the UIC riding comfort limits graph ("Lines of constant riding comfort at different speeds") is used to specify IL for the longitudinal level of 200-m track segments (figure 3) [16]. When the maximum allowable speed of quality class K2 (120 km/h), is considered, the IL equals 2.1 mm. When the maximum speed is considered, failure limit values become more conservative. In this way, all possible failures in the allowable speed range for each track class are considered.

To find the best fitted probability distribution function, we used STATGRAPHICS software. To obtain applicable results from our analysis, we only considered main distributions such as Weibull, normal/lognormal, exponential, etc., omitting other theoretical distributions.

We applied the Kolmogrov Smirnov "goodness of fit" test to measure the closeness of the fit. This test is used for continuous random variables and compares the empirical distribution function of a random sample with a hypothesized theoretical distribution function. The K-S test is based on the maximum vertical distance between the hypothesized and the empirical distribution function. If the K-S value is too large, the hypothesized distribution (null hypothesis) should be rejected [17].

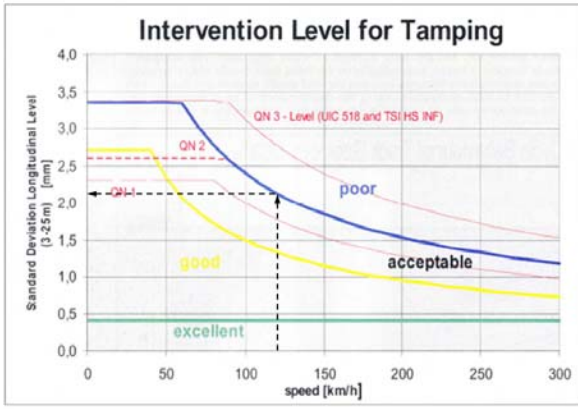


Figure 3: Lines of constant riding comfort at different speeds [16]

5. Results:

To provide an overview of the frequency of tamping, histogram of the standard deviations of longitudinal level before tamping is plotted in figure 4. The red line represent the limit defined by UIC for poor riding comfort at 120 km/h, the maximum allowable speed in the track quality class K2. Based on the data, we also determined the probability density function (pdf) (see figure 4). The probability density function of tamping execution in quality class K2 follows a lognormal distribution with a Kolmogorov Smirnov value of 0.051. As shown in the figure, the majority of tamping was executed around the defined failure limits (2.1 mm) which is classified as poor track condition in UIC. However, a substantial amount of tamping is done at a much higher value than is expected from a riding comfort point of view.

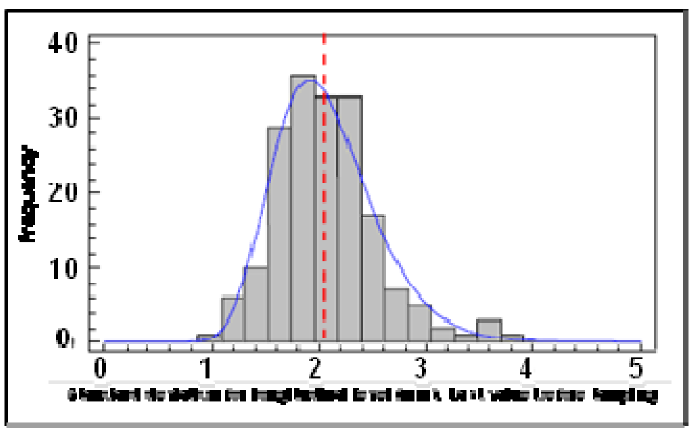


Figure 4: Probability density function of tamping execution at different level intervals

To evaluate tamping efficiency and to understand the reduction of longitudinal level deviations caused by tamping, we plotted all tamping points in the UIC “Tamping Intervention” graph; the result appears in figure 5. This evaluation shows that the tamping efficiency in the majority of the segments falls into the categories of either good or bad. However, a number of points are close to no registered tamping effect.

Figure 6 (a & b) evaluates the contractor performance from 2004 to 2010 on a case study line (a) and a reference line in central Sweden (b). It should be noted that the contractor is the same for both lines, but the contracts are different.

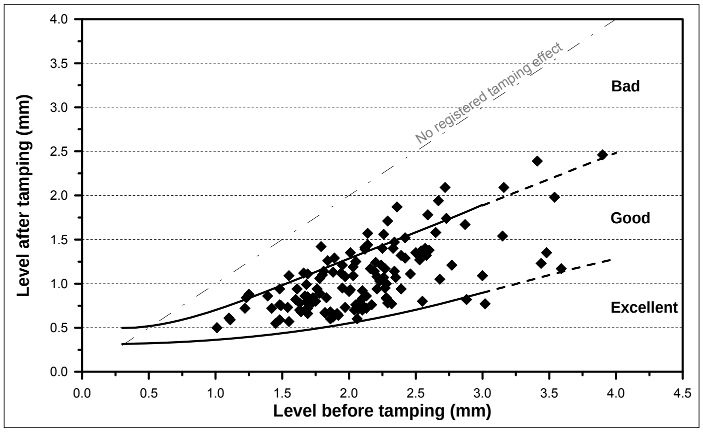
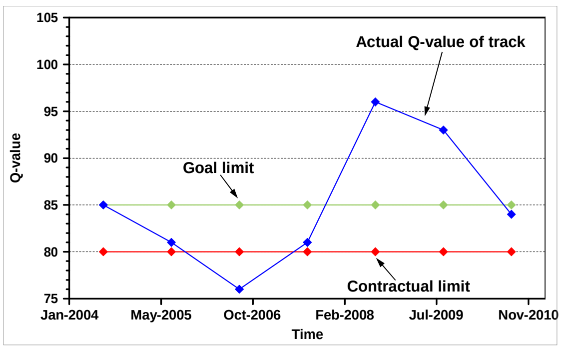
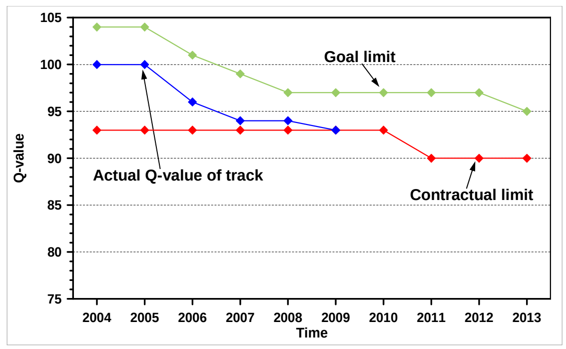


Figure 5: Efficiency of tamping



a) The contractor's performance on the "case study line".



b) The contractor's performance on a reference line in central Sweden.

Figure 6: Evaluation of the contractor's performance

6. Discussion:

The case study was designed to analyze the efficiency of track geometry maintenance in Trafikverket. While data were available from 2007 to 2009, for more precise evaluations, data for a longer period are required. Moreover, data should be reliable and accurate, and in this case, the contractor of the line had not reported all corrective tamping. To compensate for this, we used graphical inspection data and expert judgment.

The standard deviation for the longitudinal level at which tamping is executed varies extensively during the period examined (see figure 4). Tamping is sometimes executed at a very low level and is, therefore, not motivated by riding comfort. On other occasions, tamping has been conducted at levels exceeding the riding comfort limit; on still other occasions, tamping has not been executed until almost double the level of the riding comfort limit for standard deviation of the longitudinal level is reached. Although, tamping is not performed simply because of longitudinal level faults, this large variation indicates that its execution is not optimally planned.

The evaluation of tamping efficiency (figure 5) reveals that efficiency is quite low in some segments. Possibly, only parts of the segment are tamped, not the entire section, but to confirm this, we need more information. Alternatively, these particular segments could have bad sub-structure conditions. It should also be noted that the assessment of tamping efficiency is based on the Austrian railway results which, in turn, are based on different substructure conditions and a dissimilar maintenance strategy.

To explore the reasons for the high variability in tamping efficiency, we assessed the effects of a number of factors. The speed and axle load are the same for all track segments. To assess the effect of ballast age in tamping efficiency, we divided all sections into groups based on the ballast age. Then we evaluated the tamping efficiency of each group by plotting its data in tamping intervention graph, finding no clear effect from ballast age. A comparison of tamping efficiency between the ballast ages of 1987 and 1992 in class 2 appears in figure 7.

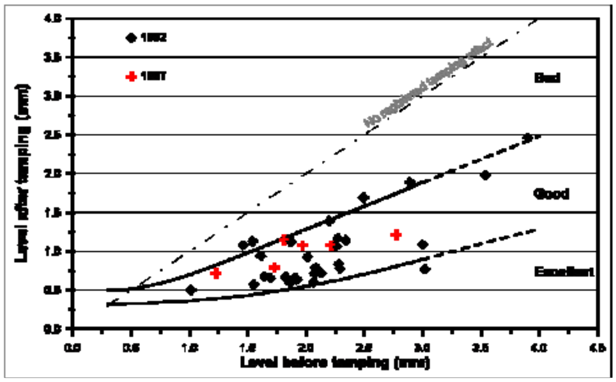


Figure 7: Comparison of ballast age in tamping efficiency

Tamping is carried out based on the Q index value and C-fault. Execution of tamping with no reliability and life cycle cost (LCC) analysis can be one possible reason for the lack of tamping efficiency. Reliability and LCC analysis can help to specify cost-effective maintenance limits, a main criterion for identifying optimal maintenance and inspection intervals. Assessment of the probability of failure occurrence over time can also help optimize maintenance planning and reduce maintenance cost.

The comparison of contractor's performance on two different lines (see figure 6) shows different maintenance policies. With the defined contractual and goal limits, the size of the associated penalties and bonuses will encourage the contractor either to be as close as possible to the lower contractual limit or to maintain a level above the goal limit. To interpret this, different factors such as maintenance budget, functional requirements stated in the contract, amount of bonus and penalties mentioned in the contract, technical issues, and maintenance decision criteria should be considered.

7. Conclusion:

The study concludes the following:

- Available and accurate data on geometry conditions and performed maintenance actions are the main requirements of track degradation analysis. However, the data available for this study are inadequate for precise degradation analysis;
- The decision-making process for the execution of tamping does not use all defined limits for geometry parameters;
- Evaluation of the standard deviation for the longitudinal level at which tamping is executed indicates that the execution of tamping is not optimally planned;
- Execution of tamping is highly dependent on the condition data and there is no well-structured track degradation analysis that helps to plan for maintenance in the long term;
- The structure of the contract, such as the maintenance budget, the defined goals and contractual limits, the size of the associated penalties and bonuses, can have a major effect on the efficiency of maintenance strategy.

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