Tamping Planning in Railway Maintenance

Improvement Potential for Optram as Decision Support

Master of Science Thesis in the Master's Programme Geo and Water Engineering

SOFIA LANDER & JOHAN PETERSSON

Department of Civil and Environmental Engineering
Division of GeoEngineering

Road and Traffic Group

CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2012

Master's Thesis 2012:63

MASTER’S THESIS 2012:63

Tamping Planning in Railway Maintenance

Improvement Potential for Optram as Decision Support

Master of Science Thesis in the Master’s Programme Geo and Water Engineering

SOFIA LANDER & JOHAN PETERSSON

Department of Civil and Environmental Engineering
Division of GeoEngineering
Road and Traffic Group
CHALMERS UNIVERSITY OF TECHNOLOGY

Göteborg, Sweden 2012

Tamping Planning in Railway Maintenance
Improvement Potential for Optram as Decision Support

Master of Science Thesis in the Master's Programme Geo and Water Engineering
SOFIA LANDER & JOHAN PETERSSON

Examensarbete / Institutionen för bygg- och miljöteknik,
Chalmers tekniska högskola 2012:63

Department of Civil and Environmental Engineering
Division of GeoEngineering
Road and Traffic Group
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone: + 46 (0)31-772 1000

Cover:
New railroad section north of Göteborg where tamping work is in progress.

Department of Civil and Environmental Engineering
Göteborg, Sweden 2012

Tamping Planning in Railway Maintenance
Improvement Potential for Optram as Decision Support

Master of Science Thesis in the Master's Programme Geo and Water Engineering

SOFIA LANDER & JOHAN PETERSSON
Department of Civil and Environmental Engineering
Division of GeoEngineering
Road and Traffic Group
Chalmers University of Technology

ABSTRACT

Optram is a computer software for evaluation of track geometry quality data, used as a decision support in planning and follow-up of tamping maintenance for Swedish railways. The software was introduced at the Swedish Transport Administration year 2009 but has not reached the intended number of users. The purpose with this thesis is to suggest how Optram can be improved as a decision support in the tamping maintenance process. Interviews have been held with maintenance planners to receive their impressions of Optram and identify problems in the process. The result has indicated that the transition from previous analogue evaluation of track geometry quality to digital evaluation with Optram is a threshold for maintenance planners. Further, a desire for an advising function in Optram is expressed. Identified problems in the process are e.g. lack of long-term tamping strategy and difficulties to acquire track possession time. Concluding recommendation for this thesis is to develop two new functions in Optram; a Tamping Recommendation Model suggesting tamping sections for short-term planning based on a target Q-value or a given budget, and a Track Geometry Quality Degradation Model predicting the long-term effects of different tamping strategies.

Key words: Optram, Tamping Maintenance, Track Geometry Quality, Q-value

Tamping Planning in Railway Maintenance
Improvement Potential for Optram as Decision Support

Master of Science Thesis in the Master's Programme Geo and Water Engineering

SOFIA LANDER & JOHAN PETERSSON
Department of Civil and Environmental Engineering
Division of GeoEngineering
Road and Traffic Group
Chalmers University of Technology

ABSTRACT IN SWEDISH

Optram är en programvara för utvärdering av spårlägesdata och används som beslutsstöd för planering och uppföljning av spårriktning på svenska järnvägar. Programmet introducerades på Trafikverket år 2009 men har inte använts i planerad utsträckning. Syftet med detta examensarbete är att föreslå hur Optram kan förbättras som beslutsstöd i spårriktningsprocessen. Intervjuer har genomförts med underhållsplanerare för att sammanställa deras intryck av Optram och kartlägga problem i spårriktningsprocessen. Resultatet har visat att övergången från tidigare analoga mätdata till Optram uppfattas som en tröskel för en del underhållsplanerare. Dessutom har en önskan om en rådgivande funktion i Optram uttryckts. De problem som identifierats i spårriktningsprocessen är bl.a. bristande långsiktig strategi samt begränsad tillgång på banarbetstider. Avslutningsvis har två konceptuella modeller utvecklats; en beräkningsmodell som rekommenderar spårriktningssträckor utifrån ett önskat Q-värde eller en given budget, samt en prognosmodell som beräknar förväntad spårlägesnedbrytning för att visa långsiktiga effekter av olika spårriktningsstrategier.

Nyckelord: Optram, spårriktning, spårlägeskvalitet, Q-värde

Table of contents

ABSTRACT I

ABSTRACT IN SWEDISH III

TABLE OF CONTENTS V

PREFACE VIII

NOTATIONS IX

ABBREVIATIONS X

1 INTRODUCTION 1

1.1 Background 1

1.2 Purpose and goal 1

1.3 Research questions 1

1.4 Delimitations 1

2 METHODOLOGY 3

2.1 Literature study 3

2.2 Study visits 4

2.3 Interviews 4

2.4 Evaluation of results 5

2.5 Exemplification of problem solutions 5

3 THEORY 7

3.1 Railroad track 7
3.1.1 Track components and geometry 7
3.1.2 Track irregularities 9
3.1.3 Consequences of track irregularities 9

3.2 Railway tamping 11
3.2.1 What is tamping? 11
3.2.2 Different types of tamping machines 12
3.2.3 Tamping in practise 13

3.3 Measuring method and evaluation of track irregularities 14
3.3.1 Measuring track geometry quality 14
3.3.2 Digital evaluation with Optram 17
3.3.3 Analogue evaluation with PDF-diagram and lists 20

3.4 Tamping in a maintenance contract 20
3.4.1 Project delivery method 21
3.4.2 Preventive and corrective maintenance 21

3.5 Tamping maintenance process 22
3.5.1 Planning 23
3.5.2 Follow-up 24

4 RESULTS 25
4.1 Improvement potential in the tamping process 25
4.1.1 Lack of long-term strategy 25
4.1.2 Low margin in tenders 26
4.1.3 Limitations with mean Q-value 26
4.1.4 Difficulties to acquire possession time 27
4.1.5 Lack of follow-up methods 28
4.2 Present state description of Optram 28
4.2.1 Optram's current usability 28
4.2.2 Education possibilities 29
4.3 Desired functions in Optram 29

5 DISCUSSION AND ANALYSIS 31
5.1 Improvement potential in the tamping process 31
5.1.1 Lack of long-term strategy 31
5.1.2 Low margins in tender 32
5.1.3 Limitations with mean Q-value 32
5.1.4 Difficulties to acquire possession time 32
5.1.5 Lack of follow-up methods 33
5.2 Evaluation of Optram's present state 34
5.2.1 Optram's current usability 34
5.2.2 Education possibilities 34
5.3 Desired functions in Optram 34

6 RECOMMENDATION OF NEW FUNCTIONS IN OPTRAM 36
6.1 Tamping Recommendation Model 36
6.2 TGQ Degradation Model 38
6.3 Examples of how to increase the usability in Optram 40

7 REFLECTION 43
7.1 Recommendation of further studies 44

8 CONCLUSION 45

9 REFERENCES 46

APPENDIX I
APPENDIX II
APPENDIX III
APPENDIX IV

Preface

This study has been conducted as a literature and interview study in order to contribute to the development of the software Optram. The thesis work has been carried out from January 2012 to June 2012 at the Department of Civil and Environmental Engineering, Division of GeoEngineering, Chalmers University of Technology, Sweden and at the Swedish Transport Administration, Göteborg.

Tomas Johansson has been supervising at the Swedish Transport Administration and the examiner has been Gunnar Lannér, Chalmers.

First of all, we would like to thank our supervisor Tomas Johansson for his support during the thesis work and to Simon Gripner, Dan Cedergårdh and Jack Hansen for their commitment and support with technical questions. Further, we would also like to thank our interview persons for sharing their time and perspectives and to the Division of Maintenance at the Swedish Transport Administration for interesting discussions and pleasant coffee-breaks.

We would also like to thank our opponents Gustav Sandqvist and Rasmus Sundberg for their support during the thesis work. At last, we would like to thank our examiner Gunnar Lannér for his encouragement and valuable advice.

Göteborg, June 2012

Sofia Lander & Johan Petersson

Notations

This section will translate some relevant railway technical terms, abbreviations and definitions that are used within the Swedish transport administration and in this thesis.

English	***Swedish***
Alignment	Sidoläge
Cant	Rälsförhöjning
C-fault list	C-felslista
Condition-based maintenance	Tillståndsbaserat underhålll
Corrective maintenance	Avhjälpande underhåll
Isolated defects	Punktfel
Link	Bandel
Longitudinal level	Höjdläge
Performance-based contract	Funktionsentreprenad
Possession time	Banarbetstid
Pre-determined maintenance	Förutbestämt underhåll
Preventive maintenance	Förebyggande underhåll
Maintenance manager	Banförvaltare
Quality list	Kvalitetslista
Sun kink	Solkurva
Swedish Transport Administration	Trafikverket
Tamping	Spårriktning
Track gauge	Spårvidd
Track geometry quality	Spårlägeskvalitet
Track geometry quality diagram	Spårlägesdiagram
Traditional contract	Utförandeentreprenad
Twist	Skevning
Valuation diagram	Värderingsdiagram

Abbreviations

Abbreviation	***English translation***	***Swedish definition***
BAP	Railroad work plan	Banarbetsplan
BESSY	System for inspection	Besiktningssystem
BIS	Information system for track compo-	Baninformationssystem
BUP	Railroad usage plan	Banutnyttjandeplan
BVF	Standard of the Swedish Transport Administration	Föreskrift
BVH	Manual of the Swedish Transport Administration	Handbok
TGQ	Track geometry quality	Spårläge

1 Introduction

This chapter will give an introduction to the thesis, starting with a background to the subject, followed by purpose and goal. Thereafter will research questions be presented to further clarify the goals and finally will the delimitations be declared.

1.1 Background

Rail transport is an essential part of a sustainable transport system in Sweden today. Passenger traffic connects regions to each other, which enables larger labour markets and enriches people´s mobility with public transports. The market for freight rail transport is increasing and competing with road transport; one freight train can take the same load of goods as 30 long-distance lorries (Näringsdepartementet, 2011).

There is an ongoing debate in media today about the current status of railway maintenance due to problems with delayed trains, especially during the last couple of hard winters. There are several components in the railway that affect the present state quality of a railroad. One important component is to maintain a good track geometry quality; that the track is straight on straight lines and curved where it should be curved. Minor track irregularities can induce vibrations in trains and thereby reduce the comfort and increase wear on other track components. More severe irregularities can induce sun kinks and cause derailment. Railway tamping is a maintenance operation performed to restore track irregularities by correcting the track geometry.

Track geometry is monitored using advanced measuring equipment to ensure that maintenance operations are taken at the correct time. Data from the measurements can be displayed and analyzed in the software Optram, acting as support for decision making regarding tamping operations since year 2009. Despite its high potential compared to the previous analogue system, the method of using Optram has not yet had a full impact in the organisation of the Swedish Transport Administration and its contractors. For this reason the Swedish Transport Administration has an interest in developing this tool to make it more useful.

1.2 Purpose and goal

The purpose with this thesis is to develop the software Optram as a decision support in the railway tamping maintenance process. The goal is to analyse Optram's improvement potential for the process and suggest new improvements.

1.3 Research questions

Following research questions have been answered in this thesis:

1. How can the current usability in Optram be improved?
2. In which parts of the tamping maintenance process does Optram have a potential to improve the process?
3. What type of new functions in Optram could be used to improve these parts?

1.4 Delimitations

The selection of issues that are studied to determine Optram's improvement potential will not cover all areas in the maintenance process that can be improved, but it will point out some selected areas that are discussed in the interviews. Further, the thesis will not consider any other maintenance operations that are normally conducted in the same contract.

The thesis will focus on preventive maintenance measures, however; corrective maintenance will be discussed in the relation to how it affects preventive measures. The physical limitations are that only welded tracks on railway lines will be considered i.e. no switches or crossings will be considered.

There is an ongoing development of functions in Optram. Since these functions are not available in the current state, they have not been taken into account in this report.

2 Methodology

This chapter will describe the methodology that has been applied during the thesis work. The first section will describe the literature that is used in the theory chapter, followed by a description of the study visits and interviews that has been performed. Finally, the two last sections will describe how the discussion and exemplification of new functions has been conducted.

As described in the introduction, the aim of this thesis is to improve the decision support regarding planning of railway tamping maintenance. The focus has been to identify problems in the process and suggest an improvement strategy to develop the software Optram.

The work with the thesis has been subdivided into the four following objectives, which will be referred to in the text in this chapter:

(1) Study and mapping of the tamping maintenance process
(2) Identification of issues in the tamping maintenance process and desire for new functions in Optram
(3) Categorisation and analysis of identified issues
(4) Exemplification of how the issues can be solved or reduced

A literature study has been a large part of this thesis, providing a theory base for the process formulation and report writing. The data collection has consisted of a qualitative interview study on different themes, the result within these themes have later been analysed to put focus on problem structures. Examples of possible ways to solve the problems have been presented and concluding recommendations regarding the future development of Optram have been formulated as the final parts of this thesis.

2.1 Literature study

A literature study has been conducted to fulfil Objective (1) and facilitate the readers as well as the authors with necessary knowledge of basic railway theory. The description of the railway track has been written for readers that are not accustomed with the technical terminology of railroad engineering and is followed by a section describing the nature of track irregularities. Both these sections are based on texts by Andersson & Berg, Corshammar and Esveld.

The next section describes tamping maintenance and track irregularities, and is based on literature by the authors mentioned above, along with the standards, manuals and other internal documents of the Swedish Transport Administration. The section that describes the software Optram is mainly based on interviews with Simon Gripner and Jan Spännar, both engineers within the Optram management group, together with internal documents produced by the Swedish Transport Administration concerning Optram. The authors have also been introduced to the Optram system.

Description of different contract types and the tamping maintenance process as a whole have been performed in order to understand how Optram is used in reality. Contracts and documentation from the procurement process have been studied to facilitate the writing of this section. Interviews with supervisor Tomas Johansson, Maintenance Engineer at the Swedish Transport Administration, have also been used. Mapping of the tamping maintenance process was found necessary to formulate the context in which the software Optram is used. Available literature is describing the tamping procedure itself while the control documents of the Swedish Transport Administration are describing the regulations and goals with tamping, but no complete description of the planning process has been available.

2.2 Study visits

Three study visits have been conducted during the work with this thesis, aiming to increase the authors' knowledge of the tamping maintenance process. They have consisted of a track irregularity inspection of an isolated defect, a track measurement with the STRIX-car and a visit to a tamping operation on new-built track. The study visits have been planned in cooperation with Jack Hansen, Maintenance Manager at the Swedish Transport Administration. Documentation from these study visits has been important while writing the theory section and for Objective (1) and (2).

2.3 Interviews

The interviews have been structured to aid in the fulfilment of Objective (2). The interview methodology has been of qualitative nature, meaning that the aim of the interviews has been rather to identify qualities, positive or negative, within the studied subject rather than measuring in what quantitative extent each of these qualities are applicable. The interview and interview analysis methodology has been developed in accordance with Ryen and Torhell (Ryen, o.a., 2004).

Structure of the interview

The interviews have been conducted as semi-structured conversational interviews. An interview manuscript with on beforehand formulated questions, has been used to ensure that certain question themes are covered, but the interviewees have also been given the opportunity to talk freely within these themes. Spontaneous questions have also been put to help the interviewees elaborate around the subjects. Six question themes have been formulated as following:

- General opinion on the field of tamping
- Formulation of goals in contract and regulating documents
- Method for evaluation of measurements
- Planning of tamping
- Execution of tamping
- Methods for follow-up

The question themes have been chosen so that the interviewees could describe problems in the whole process of tamping maintenance from their perspective, as well as specific problems when using Optram and their own thoughts on solutions. The question themes have been put in a logical order, starting with simple questions with easily accessible answers for the interviewees and continuing with increasingly specific questions.

The questions for the interview manuscript are available in Appendix 0.

Selection of interview group

The selection of interviewees has been performed in consultation with supervisor Tomas Johansson. All interviewees are in a role that connects them closely to the tamping maintenance process. The intention was to select a group with a large regional spread, covering both the roles of contractor and client i.e. the Swedish Transport Administration. All interviewees have been associated with certain maintenance contracts for one or several rail links and the goal has been to obtain a group representing different types of rail routes in terms of track standard and type of traffic.

Six interviews have been performed with five maintenance managers from the Swedish Transport Administration and one manager from an arbitrary contractor, see Table 2.1. The interviews have been conducted anonymous in order to have an outspoken discussion. The interviewee will therefore only be referred as the interviewee or with the title. Each interview session has taken approximately one to one-and-a half hour and the interviews have been recorded and transcribed. Some of the interviews have been carried out via video conference or telephone interview.

Table 2.1 Overview of the interviewees' role, region, type of contract and the type of traffic on the persons links for which they are responsible for. The abbreviation 'STA' refers to the Swedish Transport Administration.

Role	Region	Contract type	Type of traffic
Maintenance manager, STA	West	Traditional	Light goods/passenger
Maintenance manager, STA	West	Performance-based	Heavy goods/passenger
Maintenance manager, STA	East	Performance-based	Heavy passenger
Maintenance manager, STA	North	Traditional	Light goods
Maintenance manager, STA	North	Performance-based	Heavy goods
Project leader, Contractor	East	Performance-based	Heavy passenger

Presentation of interview result

The interview result is presented in Chapter 4. Due to the extent and complexity of the full interview result, only selected issues are presented and further discussed in the report. The order in the chapter is not following the interview chronology, they are sorted by the selected issues. The transcribed material has been sorted out of irrelevant information and comments, so that the interview result has become more concentrated. In this process, a certain amount of interpretation has been necessary. The results will present the identified issues in Objective (2).

2.4 Evaluation of results

The interview analysis has been conducted with the focus of answering to the fulfilment of Objective (3). All standpoints presented in the interview result has been discussed, evaluated and associated to each other to create a context. The focus has been to select issues that could be improved by developing new functions in Optram. In this way, the issues in the tamping maintenance process, which are judged as most important have been highlighted and sorted out. These issues have also been discussed in terms of where in the process they are raised and what effects they have.

2.5 Exemplification of problem solutions

The final part of this thesis has been to present examples of how new functions in Optram could contribute to eliminate or reduce the identified problems, answering to the last objective, Objective (4). The section is also a support for the following conclusions. Attempts have been made to suggest improvements both targeting direct problems for Optram users and indirect problems that arise in the tamping maintenance process. The examples of problem solutions have been developed by the authors based on the actual problems, which are stated in the discussion in Chapter 5. This section shall not be seen as the way the problems should be solved but rather how they could be solved.

3 Theory

This chapter will give the reader a theoretical background to the results. The first section will describe the basics of track geometry and define track irregularities. Thereafter will the tamping operation be explained and exemplified. The following section will describe the measuring method for track irregularities and how this is evaluated, both analogue and with digital format Optram. Finally, the last section will describe how tamping is administrated within different maintenance contract and in the planning process.

3.1 Railroad track

It is essential to understand how the railway is constructed and designed in order to understand how track geometry quality can vary over a distance. This section will explain the basic parts of a railroad track construction and its geometry.

3.1.1 Track components and geometry

There are different kinds of railway constructions, ranging from simple structures with wood sleepers and jointed rails to ballast-free tracks with welded rails (Banverket, 1995). The railway is composed of different parts with different functions, as displayed in the cross section below, Figure 3.1. Starting from the top, the different parts are described in the following section. (Andersson, o.a., 2001).

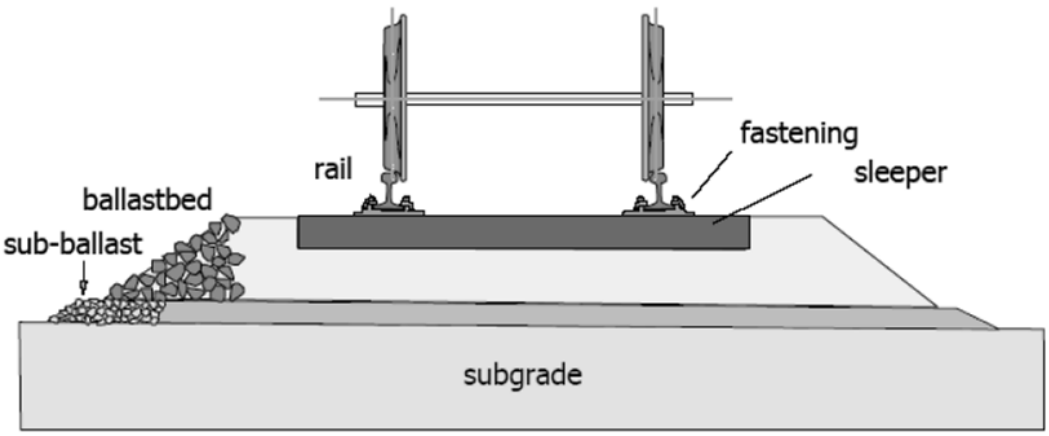


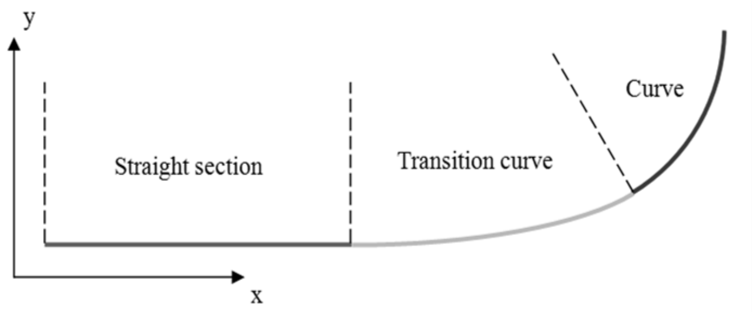
Figure 3.1 Schematic picture of the components in a railway track (UIC, 2010).

.

The rails are made of I-shaped steel bars on which the rail vehicle wheels are running. Rail sections of lengths up to 400 m are welded together to form a smooth rail with good travelling comfort. Sleepers form the support for the rails, transferring the load from the vehicles into the ballast. The sleepers are normally constructed of concrete, but wood sleepers occur on old track sections, in tunnels and on bridges. The spacing between the sleepers is normally 0.65 m.

Furthermore, the ballast bed is anchoring the track, preventing lateral and longitudinal movements as well as creating bearing capacity for the track. There are strict requirements on the characteristics of the ballast regarding hardness, grain shape and grain distribution to ensure that the desired function is achieved. Apart from being stable, the ballast bed must also have elasticity and good drainage capacity to lead off rain water. It also has to ensure ability of adjustment. Finally, the sub-ballast is the primal track foundation, preventing vertical movements and its thickness depends on the underlying subgrade. To avoid movements in the subgrade due to frost heave the sub-ballast also has an isolating function and the thickness is therefore depending on in what climate zone the track is situated.

Track geometry is composed by straight lines and curves with different radius depending on the maximum speed on the track, this is regulated in the guidelines of the Swedish Transport Administration. Between a straight line and a curve is a transition curve where the radius is varying, from infinite at the connection to the straight section to equal of the curve at the curve connection, see Figure 3.2. On Swedish railway lines the curves can have a radius of 500 - 20 000 m (Andersson, o.a., 2001). To compensate for radial acceleration forces in the curved sections a cant is added on the outer rail in the track cross section, see Figure 3.2. Since the acceleration force is depending on the speed with which the train travels through the curve, each curve has a design speed. Nevertheless it is possible to travel with different speeds through the curve, the result will be a residual acceleration force experienced by the passenger/goods and uneven wear on the rails.



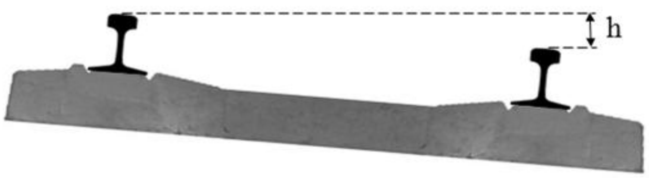


Figure 3.2 *Above*: The different geometric elements of the railway track. *Below*: A sleeper with cant in a curve, the left rail is the outer rail in the curve. The cant is denoted as h (Andersson, o.a., 2001).

The transition between straight track and track with cant constitutes of a ramp placed in the transition curve on the outer rail. In the ramp, the cant is increasing with certain steepness depending on the length of the ramp and target value of cant; this steepness is referred to as twist. The twist accelerates the rail vehicle into a rotation and therefore the rail is subject to large forces from the rail vehicle wheels (Andersson, o.a., 2001).

3.1.2 Track irregularities

Deviations from the projected track geometry exceeding tolerated levels are defined as track irregularities (Corshammar, 2008), see Figure 3.3. The projected or nominal track geometry is the planned geometry of the railway track, referring both to horizontal-plane geometry and vertical alignment in the cross-section.

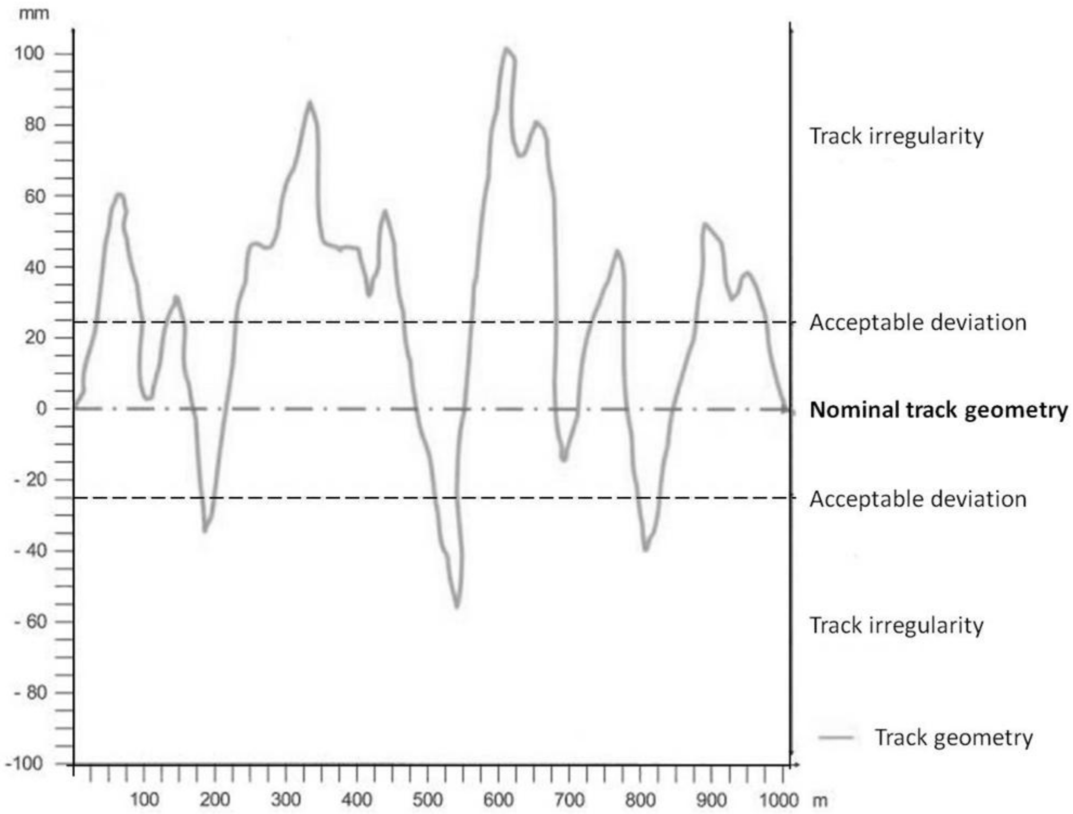


Figure 3.3 Illustration of track irregularities. The dashed and dotted line indicates the nominal track geometry (Corshammar, 2008).

For a newly built track the tolerances for track irregularities are very low, only a couple of millimetres. As the trains start running on the track larger deviations will arise, horizontally due to track movements and vertically due to crushing of the ballast Track irregularities are important to maintain regularly, as the irregularities can be too difficult and expensive to restore if they have become too extensive, in which case a larger reinvestment measure is necessary rather than simple maintenance (Banverket, 1997).

3.1.3 Consequences of track irregularities

Track irregularities can be classified into different groups depending on their extension in length and type of irregularity.

The shortest irregularities, as referred to in the standards of the Swedish Transport Administration, are the isolated defects (Banverket, 1997). An isolated defect is a single point value where the track deviation norms are exceeded and can concern cant, twist or track gauge. Isolated defects induce dynamic forces in the vehicle, which can cause comfort problems for passengers. Further, the repeated passage of trains over an isolated defect can cause local extreme wear on the track, resulting in fatigue of rails, fastenings and sleepers and eventually causing fractures on the rails and thereby a great risk of derailment. Due to the nature of the isolated defects they are often subject of corrective maintenance.

Short wave irregularities are defined as irregularities with a wave length of 1-25 m, here alignment and longitudinal level are sorted. The consequences of short wave irregularities are similar to those of the isolated defects however; they rather create vibrations of a couple of seconds than inducing dynamic forces.

Long wave irregularities are defined as irregularities with a wave length exceeding 25 m (Banverket, 1997). These types of irregularities mainly cause problems at high speeds, creating swaying movements of the wagons which can cause nausea for passengers. Moreover, long wave irregularities can be difficult to detect with the accelerometers that are used as measuring equipment.

Track irregularities can increase the risk of sun kinks, which is a phenomenon when the track gets buckled. This is caused by length expansions in the track due to a temperature change. Welded track has no margins to expand, which induces large forces in the sleepers at high temperatures and when the horizontal forces are too large the track will buckle and cause a sun kink, see an example of this event in Figure 3.4. When trains are crossing isolated defects, caused by track irregularities, it will induce large forces to the track, which can trigger sun kinks. Sun kinks are serious events that can cause derailment (Trafikverket, 2010).

Figure 3.4 Illustration of a sun kink.

There are several advantages with minimizing track irregularities. By limiting the forces that affect tracks due to isolated defects, the wear of several track components is reduced and the operation safety is increased for the railway. This will have positive long-term effects and increases the track's life-span[1]. It will also affect the comfort for passenger trains due to disturbing vibrations.

[1] Dan Cedergårdh, Track Engineer, Swedish Transport Administration. Interview 2012-04-27

3.2 Railway tamping

Railway tamping maintenance is conducted to restore track irregularities and is the most common form of track maintenance (Esveld, 2001). The following section will describe the process of railway tamping, different tamping vehicles and how tamping is conducted today in Sweden.

3.2.1 What is tamping?

Tamping can be explained as compaction of the ballast in the railway track to increase the supportive effect from the ballast on the sides of and under the sleepers. The tamping vehicle has a tamping tool that consists of claws of picks that are inserted in the ballast on each side of the sleeper after which the picks are vibrated, creating small movements in the ballast bed which adjusts the position of the individual aggregates to reduce cavities, see Figure 3.5. The other vital part of the tamping machine is the lining tool, consisting of a gripping device with steel rolls tracking the rail. As the tamping tool creates vibrations in the ballast bed, the lining tools adjust the position of the rails, by which the whole track is straightened. Tracking wheels are collecting geometric information to the on-board measuring system, which are controlling the gripping devices pulling the rails so that the correct horizontal and vertical position is restored (Esveld, 2001).

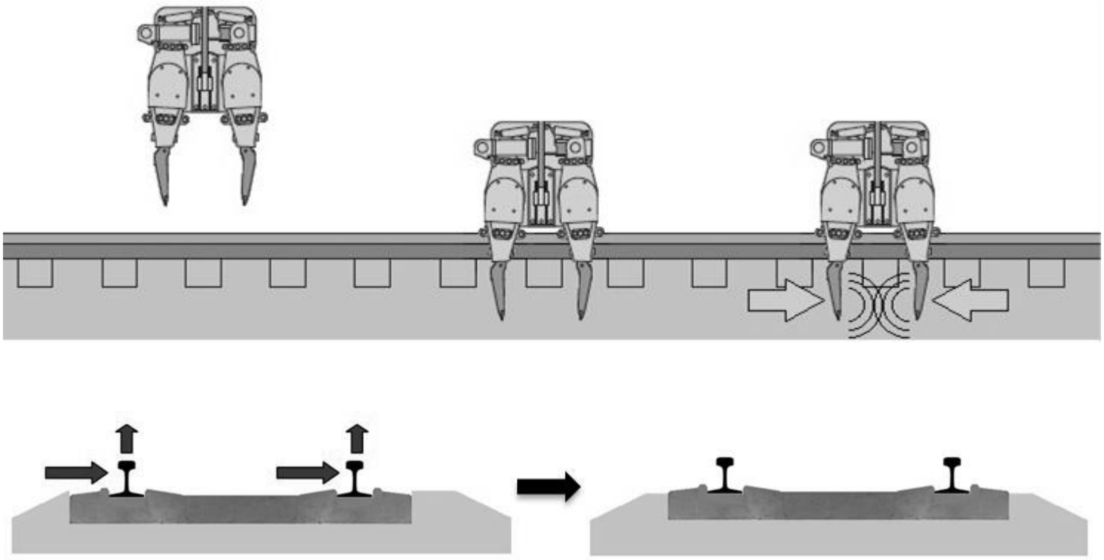


Figure 3.5 *Above:* Principal sketch of tamping action. The tamping tool stops over a sleeper after which the picks are pressed down in the ballast, vibrated and squeezed around the sleeper. *Below:* The current position of the sleeper is adjusted horizontally and vertically so the correct position in the cross section is established

The control system of the tamping machine commonly uses a three- or four-point measuring system for identifying the geometry (Esveld, 2001). The machines can have both mechanical and digital systems. Using the relation between measuring points, consisting of earlier mentioned tracking wheels, horizontal and vertical deviations from a line intersecting the points are identified. The effectiveness of this practice is depending on the length of the tamping vehicle measuring basis. The greater the distance between the measuring points, the better the accuracy. Figure 3.6 below illustrates the lining principle which can be described as smoothening, as the irregularities are evened out in relation to the existing geometry.

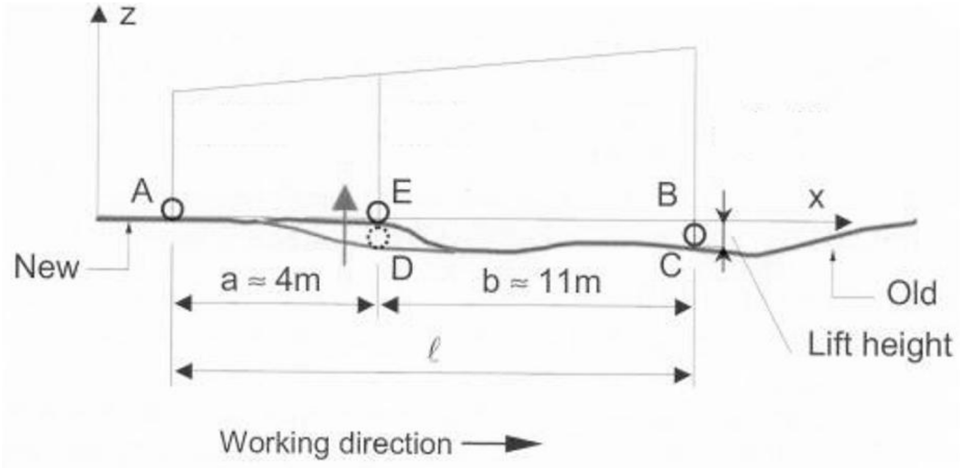


Figure 3.6 Illustration of how the tamping vehicle smoothens out irregularities. A Theurer 07-32, commonly used tamping vehicle, has a measuring basis of a = 4 m and b = 11 m (Esveld, 2001).

The lining principle of smoothening is not equally efficient when it comes to track irregularities with larger deviations from the projected geometry. As a result of many subsequent smoothing tamping actions, the railway track can be centimetres out of position on longer sections (Corshammar, 2006).

To avoid this problem, coordinate controlled railway tamping can be conducted, either restoring the track to its projected line or creating an adapted optimal geometry from the existing one. Another type of tamping is facilitated by laser measurements from a probe vehicle driving in front of the tamping vehicle, creating a longer measuring basis for the vehicle (Esveld, 2001).

3.2.2 Different types of tamping machines

Though most tamping machines operate in a way similar to the one described above, there are some differences. Tamping machines can be subdivided depending on their progression speed which is mainly affected by how many "claws" the machine is equipped with and thereby how many sleepers can be tamped simultaneously. In the table belowTable 3.1, a few examples of tamping machines are listed with corresponding working speeds and the picture in Figure 3.7 shows an example of a tamping machine.

Table 3.1 Examples of different tamping machines with corresponding work speeds. Edited: (Matisa, 2012) (Esveld, 2001).

Model	Type	Maximum working speed
Matisa B20-75	Single sleeper, intermittent	500 m/h
Matisa B45D	Double sleeper, intermittent	1200 m/h
Plasser & Theurer 09-32 CSM	Double sleeper, continuous	1600 m/h
Plasser & Theurer 09-3X	Triple sleeper, continuous	2200 m/h

Further, the machines can be divided depending on whether they are continuous action tamping machines or intermittent action tamping machines. A machine operating intermittently is tamping a group of sleepers, moving along for a couple of meters and then stopping to perform tamping on the next group of sleepers, resulting in an irregular running pattern which can be a problem of the working environment for the machine operators. The continuous action tamping machine on the other hand is equipped with a tamping trolley under the machine itself, so the trolley can move intermittently while the machine itself has a constant speed.

Figure 3.7 Tamping vehicle in operation between Göteborg and Trollhättan. The vehicle is a Matisa B40D with double sleeper tamping tools and intermittent working pattern.

There are also special tamping machines for switches and crossings, equipped with displaceable tamping claws to enable movement of the tamping tools to the exact point to be tamped, as normal tamping machines can only operate on line sections. For minor irregularities tamping can also be performed by tractors and excavators equipped with tamping tools (Esveld, 2001).

3.2.3 Tamping in practise

Tamping in Sweden has to be carried out according to the rules and limit values formulated in the regulations of the Swedish Transport Administration. Most relevant of these regulations is the standard BVF 587.02, stating the limit values for residual irregularities after executed tamping.

According to Hansen[2], different documents provide valuable information for the tamping crew during operation. The list of ordered tamping units is essential and gives information of at what length section to start and stop tamping. It is ordered by the tamping planner, who in some contracts is the maintenance manager of the Swedish Transport Administration while in other cases is an employee of the contractor. What further is important is a valid time plan for the planned working shift, where the operators can see planned passages for other trains and by this enable for the crew to move the tamping machine in sufficient time to an off-branching side track. A curvature card is yet another document giving valuable information. The curvature card is a simplified map of the railway route, stating start and end points for different geometrical elements. Due to the fact that the tamping machine is bound to the track and only can move forward or back, such a kind of simplified map is in most cases sufficient.

When the tamping order is executed this shall be reported through the information system BIS, along with information on deviations from the original order. This is done to make the information available for follow-up and planning of new tamping measures (Banverket, 2004).

3.3 Measuring method and evaluation of track irregularities

In order to keep a safe track geometry quality on the railway it is important to perform continuously measurements. Track geometry quality can be measured manually (unloaded) e.g. during maintenance work or with an automated track recording car (loaded), which will be in focus in this section. The measuring results are presented graphically and in a list format. This information is used to identify critical parts of a railway link and to evaluate what type of measure that should be taken e.g. if it is critical deviations that requires immediate measure or if it can be adjusted during the next planned maintenance work. This is used as a basis for the long-term preventive maintenance plan and to control its effect. The rules and restrictions for controlling track geometry quality are stated in BVF 587.02 (Banverket, 1997).

3.3.1 Measuring track geometry quality

Track geometry quality measurements are performed continuously during the year and the recommended intervals are to measure about five times per year. There are two types of recording cars that are used to measure track geometry quality in Sweden today, in total one STRIX car and three IMV100 cars. The STRIX car is the most advanced and will be further described.

The STRIX-car is originally a café wagon RB5 from 1940 that was rebuilt 1973 to measure overhead lines. In 1998 it was rebuilt again and equipped with a more advanced measuring system that is still used today, see Figure 3.8. This system is based on an accelerometer and optical instruments that measure the deviations of longitudinal level. Further, alignment for each rail is measured from the wagon's wheel to a reference point. The system registers data four times per meter. The STRIX-car also measures the rail profile and overhead line. In the back of the car there is a video recorder that runs continuously and films the surroundings e.g. to see stations and vegetation (Banverket, 1997).

[2] Jack Hansen, Project leader, Swedish Transport Administration. Interview 2012-03-27

Figure 3.8 Pictures of the recording car STRIX. The picture to the right shows the measuring equipment.

The outcomes from STRIX-measurements regarding track geometry quality are used in a system to generate numerical characteristics of the track. There are several types of errors that affect the track geometry quality and these parameters are used to identify both isolated defects and combined errors. Signals from the recording car are sorted with a filter with different wavelengths and then presented as characteristics that describe the track geometry quality (Banverket, 1997).

Longitudinal level deviations can affect a train in two different ways. If one rail is higher than the other it will generate a rotating movement in the wagon and if the heights deviations are equal for both rails it will generate a rolling movement in the wagon's direction. These error modes are described by the short-wave longitudinal level of right and left rail and by the mean value of both rails as long-wave longitudinal level. The cant is calculated with a gyroscope in the recording car that measures the angle between the ground and wagon. This value is differentiated to give the twist over 3 or 6 m basis (Banverket, 1997).

Isolated defects are categorized in terms of class A-, B- and C-faults. Class A-faults describes the allowed limits for a new build track and the limits in class B should be a limit for when measures should be taken. Class C-faults are serious events that can cause derailment and should be fixed as soon as possible and depending on seriousness speed reduction or total stop for trains should be considered. The limits for A, B and C-faults depends on a track's quality class. These are denoted as K0, K1, K2,...,K5 and refer to the highest allowed speed on the track, where K0 is allows the highest speeds. It is optimal that deviations never reach class B in the first case (Banverket, 1997). An example of the limits for longitudinal levels is illustrated in Figure 3.9, the red circle marks the C-fault limits for short wave alignment deviations e.g. deviations larger than 5 mm for a K0 quality class is classified as a C-fault.

			Avvikelse från grundvärde (mm)							
Kvalitets-klass	sth loktåg km/tim	sth snabbtåg km/tim	Sidoläge					Spårvidd		
			Kortvågiga fel 1-25 m våglängd			Långvågiga fel (riktvärden)		Avvikelse från nominellt värde 1435 mm		
			A	B	C	A	B	A	B	C
K0	145 -	185 -	2	3	5	5	10	±2	±5	+15,-5
K1	125 - 140	160 - 180	2	4	6	5	10	±2	+7,-5	+20,-5

Figure 3.9 Extract from the BVF587.02 standard. The circled column is stating the limit value for track irregularities in mm, denoted as C-faults.

The track geometry quality over a longer distance can be described numerically with a quality coefficient, Q-value. It is based on standard deviations for alignment and interaction between longitudinal level and cant. Standard deviation is a common way of describing track irregularities in Europe and it describes how the deviations over a certain distance. The standard deviations are calculated continuously over a distance of 200 m. The Q-value is calculated by using the following equation (Banverket, 1997):

$$Q = 150 - 100 * \left(\frac{\sigma_H}{\sigma_{Hgr}} + 2 * \frac{\sigma_S}{\sigma_{Sgr}}\right)/3$$

Where:

Where:	Q	Q-value [-]
	σ_H	Mean standard deviation for longitudinal level
	σ_S	Mean standard deviation for interaction
	σ_{Hgr}	Comfort limits for for σ_H
	σ_{Sgr}	Comfort limits for for σ_S

The interval for Q used in practise is set to $0<Q<120$ but it has a theoretically maximum of 150. A high Q-value indicates a good quality of the track. Notice that interacted deviation, σ_s has a larger impact on the Q-value than the longitudinal level σ_H. Recommended Q-values depends on the quality class of a track and is shown together with a predicted degradation in Table 3.2 Recommended Q-value depending on quality class and predicted degradation (Q/year). Table 3.2.

Table 3.2 Recommended Q-value depending on quality class and predicted degradation (Q/year). (Banverket, 2004)

Quality class	Recommended Q-value	Predicted degradation (Q/year)
K0	80	4-8
K1	80	4-8
K2	75	3-6
K3	75	3-6
K4	75	2-4
K5	75	2-4

Results from the recording car are currently presented in digital and analogue format. The analogue version contains a track geometry quality diagram, here denoted as TGQ diagram, with a graphical illustration of the deviations and three documents: valuation diagram, C-fault list and a quality list. TGQ-diagram is also presented in a digital version, in the software Optram.

3.3.2 Digital evaluation with Optram

The Optram software has been in use at Swedish Transport Administration and former Banverket since 2009 and was delivered as an advanced tool for analysis of track and overhead line measurements. It is provided by Bentley Systems and is also used by the American Railway Company Amtrak. Optram is supposed to replace analogue evaluation of measurements printed as PDF-files. In the following section the measurements and tools used for planning of tamping will be described. The section is based on interviews with Gripner and Spännar[3].

Track irregularities can be complex, not always depending on deviations in one of the measured values but rather on the synergy of multiple deviations. Because of this, the Optram standard interface comprises multiple views simultaneously, to enable identification of irregularities in continuous data and discrete track elements.

The basic function of Optram is to show measured data parameters and how they are related to the standards documented in BVF 587.02. Track irregularities are plotted in relation to a centre line describing the nominal track geometry. The y-axis describes the magnitude of the irregularities and the x-axis states the position of each irregularity (km + m), see Figure 3.10.

Measurements are available for the entire Swedish railway net and can be displayed by selection of rail link and length section. For example, a rail section close to Alingsås can be found by choosing link 622, km 412 + 400 m. The navigation bar is displayed in Figure 3.10, area (a.). From the current view, navigation along the x-axis is performed using the arrow buttons in the tool field. Zooming buttons, placed left of navigation arrows, can be used to adjust the scale of the x- or y-axis. Area (b) in Figure 3.10 illustrates facility data from BIS with information about e.g. were stations, crossings and insulation joints are positioned. Some of the data displayed is relatively

[3] Interview with Simon Gripner 2012-02-27 and Jan Spännar 2012-02-28. Engineers within the Optram management group, Swedish Transport Administration

raw while other data is calculated. An example of calculated data is the Q-value of the track, which is important interpret the complex data supplied from the measurements, see Figure 3.10, and curve (c.).

The track irregularities are effects of horizontal and vertical deviations of the track which is the most basic data displayed in the Optram user interface. The horizontal and vertical deviations are showed as two sets of curves, each set containing three curves, see Figure 3.10, curves (d.) and (g.) respectively. Each set comprises displacement of the right rail, left rail and a mean value of both.

Uneven changes in horizontal and vertical position can cause twist. The twist of the track is displayed in Figure 3.10, curve (e.). Curves and transition curves are more sensitive to twist irregularities than straight sections and therefore it is of great importance to connect the twist irregularities to the track geometry. Curves (f.) in the same figure shows cant and curvature.

Information on the track gauge is important for maintaining a safe track, since deviations can cause derailment. Track gauge irregularities can be caused by displacement of the rail on the sleeper but also by wear on the rail. Figure 3.10 curve (h.) shows the track gauge.

Apart from measurements regarding the track, earlier performed maintenance operations is also important information for maintenance planning. Certain sections have to be tamped more often than others and in some sections tamping has marginal effect to the state of the track. In the view “Spårriktning” (Tamping), the date and extension of earlier tamping measures are displayed, see Figure 3.10, curve (i.).

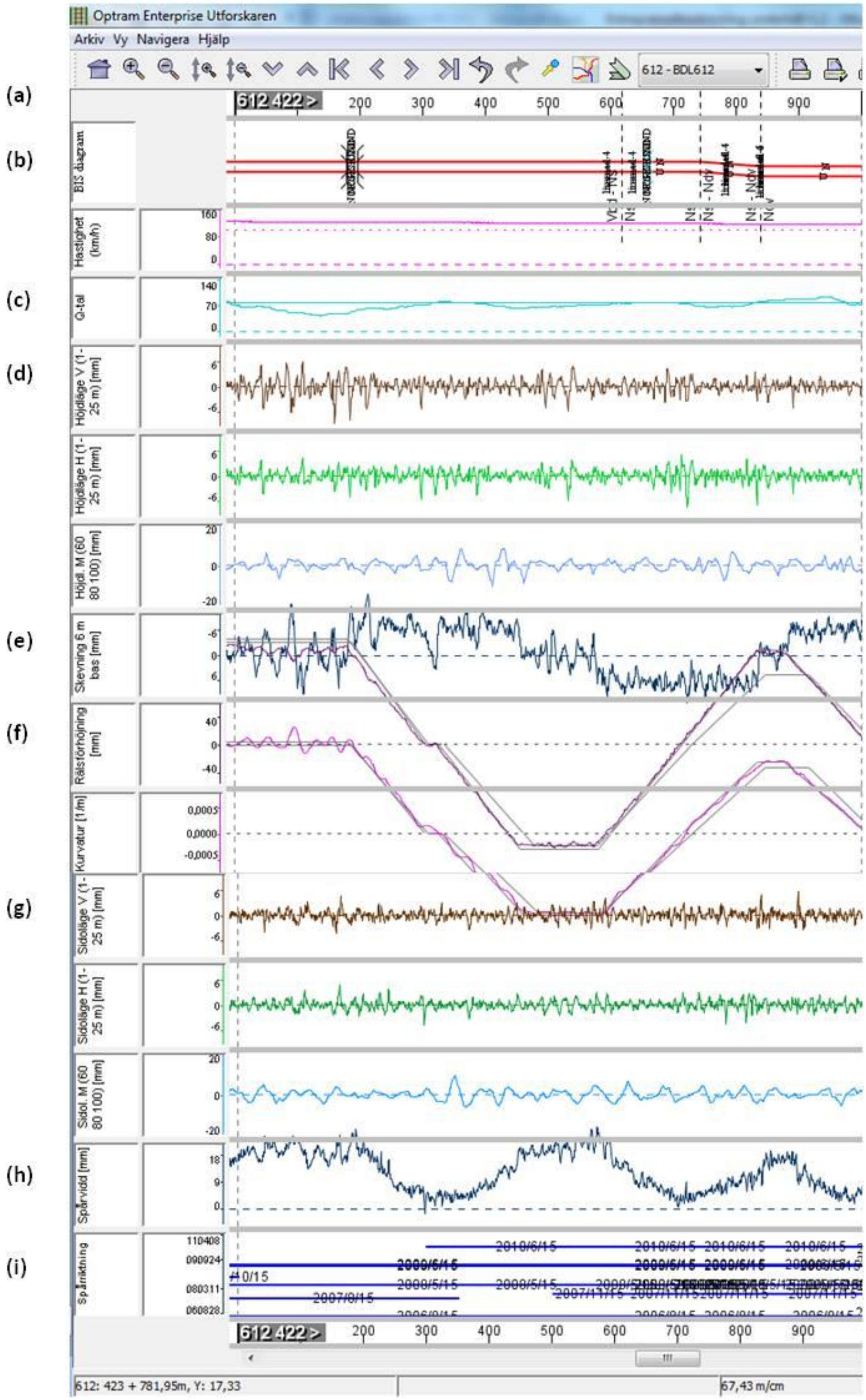


Figure 3.10 The Optram user interface with default settings.

For most railway links, measurements are performed several times a year. As a result of this, multiple measurements for each link are accessible and can be displayed one at a time or layered on top of each other in the Optram view window. By comparing several measurements, degradation trends can be shown as well as effectiveness of maintenance measures. Figure 3.11 below shows the degradation trend in form of Q-value.

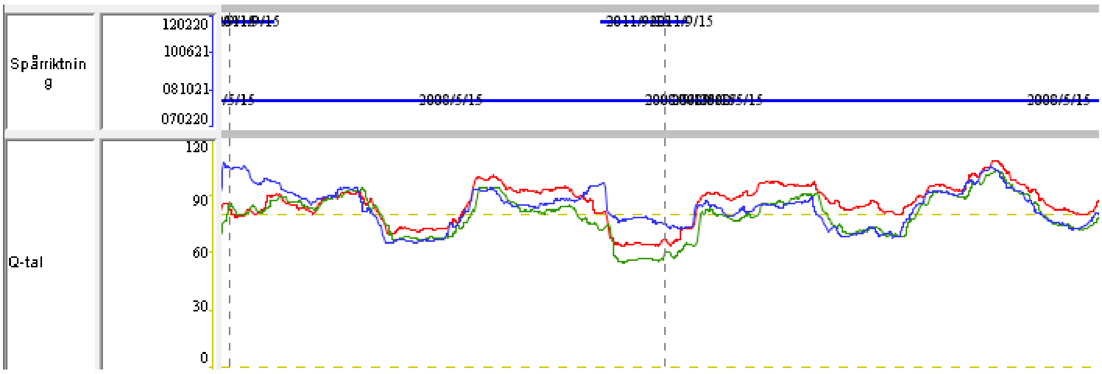


Figure 3.11 The trend analysis view setting, exemplified on Q-value. Measurements from August 2010 (red), June 2011 (green) and December 2011 (blue) are displayed. In the view above previous tamping measures are displayed and denoted with the date.

3.3.3 Analogue evaluation with PDF-diagram and lists

Analogue evaluation documents in PDF-format are sent to the Swedish Transport Administration and if necessary to the contractor. These documents consist of two diagrams; one track geometry quality diagram and one valuation diagram. Further, two documents in list form, quality list and C-fault list are included. The track geometry quality diagram is the original layout that the Optram view is based on and the illustrations are similar, see Appendix II. However, the track geometry quality diagram does not provide Q-value or information about previous tamping or detailed facility information (Banverket, 1997).

The valuation diagram shows graphically the standard deviations for longitudinal level, alignment and combined errors. It also illustrates the curvature, Q-value, B- and C-faults, track gauge errors and other information about the time for measurements and distances measured, see Appendix III. The quality list is a summary of the measurements in table form. It presents the amount of B- and C-faults and track errors, per kilometre together with standard deviations and declaration of the mean Q-value between stations and for the whole link, see Appendix IV. Finally, the C-fault list contains length position of all isolated defects that are classified as C-deviations and derailment-urgent faults and are marked with bold text. This document is useful for planning corrective maintenance (Banverket, 1997).

3.4 Tamping in a maintenance contract

Tamping is normally conducted as a part of larger railway maintenance contract that also covers other areas for example change of sleepers or replacement of rails. The procurement is set up by a national board and is normally limited geographically by different corridors. Since the Swedish Transport Administration was developed, the relationship between contractor and client has changed from a regulated market to an open market with defined roles. Swedish Transport Administration has set up a goal for the maintenance business to develop and define the role as client even more and one part of this is evaluating the project delivery methods.

3.4.1 Project delivery method

Railway maintenance is normally performed in one of the following two different project delivery methods: traditional contract and performance-based contract. The main difference is that a traditional contract normally offers specific unit prices while a performance-based contract is based on maintaining a function.

In traditional contracts, the client has full responsibility for designing the maintenance operations and presents a work description on which the contractor can give a price for each unit in the tender. The design part can be supported by external consultants and should follow AMA, a reference system for the building industry. A technical description is a basis for the construction design and defines which materials and methods that should be used by the contractor.

The client's role in a performance-based contract is smaller and allows more creativity for the contractor to plan their work. An inspection is made before the contract starts by the contractor to evaluate the present standard and function of a link or facility. The contractor will then give a tender with a price for maintaining the same quality of this link or facility by the end of the contract and at annual controls. This means that the contractor should include both preventive and corrective maintenance costs in their tender.

There is a long-term goal at the Swedish Transport Administration to convert all maintenance contracts into performance-based ones. The purpose is to use the contractor's knowledge and experience and leave over the responsibility for planning operations. By letting the contractor plan resources in a more free way it could lead to a more cost efficient work. Today, the performance-based contracts are used for about half of the railway maintenance contracts in Sweden[4].

3.4.2 Preventive and corrective maintenance

For railway maintenance, the contract is divided in two main subjects, operation and maintenance, see Figure 3.12. Operation involves services to support the object's everyday function like snow clearing and leaves clean-up, while maintenance are measures that should retain or restore an object in order to maximize its lifetime. Maintenance is sub divided into preventive and corrective maintenance, where corrective maintenance involves measures against functional errors that should be fixed immediately or within a week. Preventive maintenance, on the other hand, is performed in order to decrease the probability for damage or degradation of an object. The preventive in turn is sub-divided into condition-based and pre-determined maintenance. Condition-based maintenance involves control of the actual state and measures for the object while pre-determined maintenance is conducted at certain fixed time intervals without a preceded inspection (Banverket, 2009).

[4] Tomas Johansson, Maintenance Engineer, Swedish Administration. Interview 2012-03-23

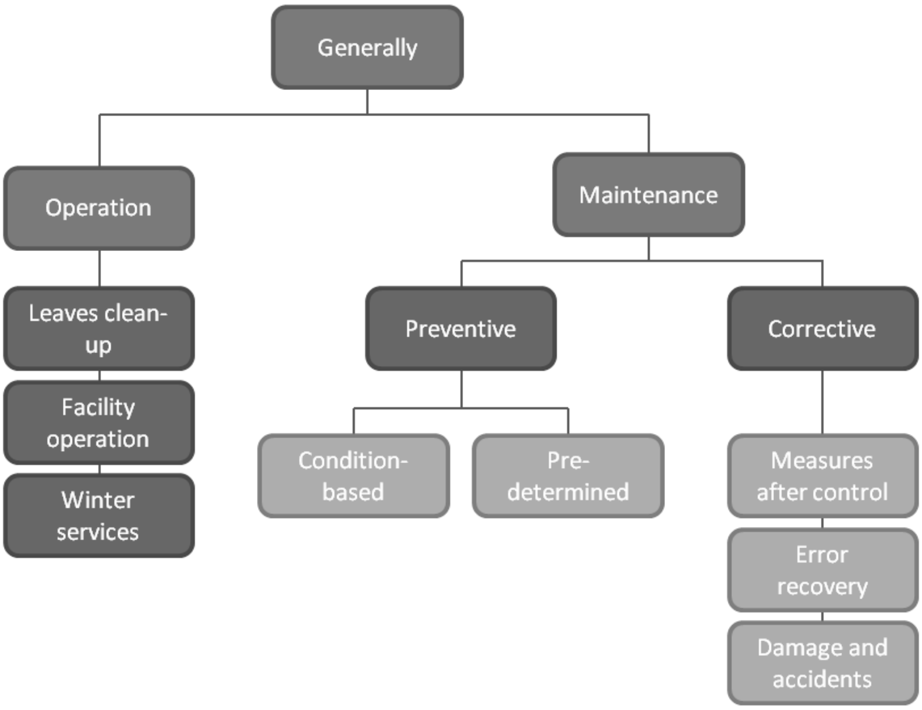


Figure 3.12 Overview of the objects in a maintenance contract. Edited (Banverket, 2009)

Tamping is performed as both preventive and corrective maintenance. In a performance-based contract the preventive part can be both condition-based and predetermined. Examples of corrective maintenance are measures against isolated defects that could be C-faults, detected by a recording car. Preventive maintenance are on beforehand planned operations conducted in continuous intervals, e.g. tamping during workweeks. The function demand regarding tamping is based on maintaining an average Q-value on a certain link or between stations. For example, if a link has an average Q-value of 75 when the contract starts, the contractor takes the economical responsibility for maintaining this value until the contract has ended. If the client wants to raise the Q-value at one part of the link then this can be managed as an additional part. It is up to the contractor to plan its own work and choose methods to maintain the function and the contractor is responsible for both corrective and preventive maintenance[5].

Fines and bonus can be used as an incitement for the contractor keep a good track quality and follow the functional demands. However, a good preventive maintenance plan will minimize corrective measures, which is an expensive and time-consuming work for a contractor in a performance-based contract (Johansson, 2012).

3.5 Tamping maintenance process

The tamping maintenance process could be illustrated as planning, maintenance, measurements and follow-up components see Figure 3.14. This section will describe how the planning and follow-up is regulated and conducted.

[5]Tomas Johansson, Maintenance Engineer, Swedish Administration. Interview 2012-03-23

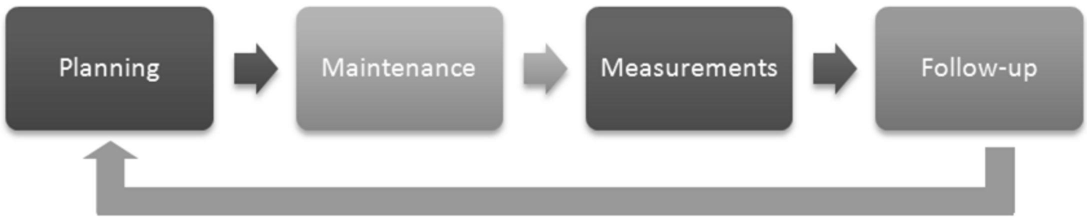


Figure 3.13 Illustration of how the tamping maintenance process could be visualized.

However, the planning and follow-up phases of tamping maintenance are not strictly regulated by the Swedish Transport Administration, only the goals that should be achieved in this process. As a result of this, there can be differences in the process, depending on what region the rail link is located and how the process is regulated in the maintenance contract.

3.5.1 Planning

Planning of tamping maintenance is conducted by the client in a traditional contract and by the contractor in a performance-based contract, although the principles should coincide. Corrective tamping maintenance is special cases were the demand is set by regulations in the standards. If the recording car reports a C-fault or a fault with risk for derailment measures has to be taken immediately. On the other hand, preventive tamping should be planned on before-hand. There are mainly two aspects to consider in the planning; evaluation of measurements and applying for possession time i.e. to acquire time for maintenance in the link’s time-table.

The method and results of track geometry measurements are described in Section 3.3 and the evaluation is regulated with recommendations in the manuals and standards, stated by the Swedish Transport Administration. However, the interpretation of these results can be arbitrary depending on the maintenance engineer and his experience of evaluating TGQ-diagrams. The process of prognosticating tamping effects is not clearly regulated in the manuals. There is only one guiding formulation in the tamping manual, saying that *“Before a final decision is taken regarding tamping, an assessment has to be made whether tamping alone is a sufficient measure.”* (Banverket, 2004).

Availability of possession time and tamping machines is necessary to consider in the planning process of tamping. Possession time can be reserved in the time-table with two different systems, BAP and BUP, abbreviations freely translated as “railroad work plan” and “railroad usage plan”. The former of the two is decided further ahead, 18 months before planned maintenance operation, while the latter is a tool for filling in available hours, set 8 weeks before the planned maintenance operation. This means that if the possession time can be reserved in BAP it will enable longer disposable time for maintenance operations, while time reserved in BUP more likely generate shorter disposable times and only enables short-term planning operations. The possibility to reserve tamping machines is highly depending on the length of the planning horizon, so whether the tamping is planned in BAP or BUP will have impact also on tamping machine availability[6].

[6] Tomas Johansson, Maintenance Engineer, Swedish Administration. Interview 2012-03-23

Available budget is another factor that will affect the amount of tamping kilometres that can be conducted.

3.5.2 Follow-up

The guidance provided for follow-up routines after tamping is given in the following extract from the Swedish Transport Administration manual; *"It is important to verify […] whether expected results are reached […] and to gain knowledge on if, and in that case when, recurring irregularities may arise. The immediate results of performed tamping can be followed up by mechanized track monitoring, conducted directly in relation to the tamping."* (Banverket, 2004).

There are no other clear routines formulated in the manual of how follow-up should be conducted to evaluate the effect on the track geometry quality. However, there are economical follow-up after a performed tamping operation. In traditional contracts, it is common to evaluate a performed operation at the next measurement with the recording car. It is then possible to see the effect in a TGQ-diagram e.g. by evaluating the Q-value or by comparing the quality lists. Performance-based contracts, on the other hand, have clear regulations stated in the contract i.e. to maintain a certain Q-value for a link or between stations. This is controlled annually and in the end of the contract.

4 Results

This chapter will present results from the interviews. The first section will describe the selected issues that Optram has a potential to improve, within the tamping maintenance process. The second section will describe opinions about Optram's current usability and finally, the third section will present desires of new functions that has been expressed during the interviews. Since the interviews are conducted anonymously there will not be any references to the interviewed persons in this text. Some quotations are inserted in the text to exemplify the context however; these will only be referred with interviewee's title.

4.1 Improvement potential in the tamping process

The general opinion about the present tamping process is positive among the interview persons. Most of them claim that they are satisfied with the track geometry quality with respect to the given circumstances on their respective link. However, there is a potential for improvements.

4.1.1 Lack of long-term strategy

There is a broad consensus among the interviewees that a long-term strategy is necessary for planning tamping operations. Only working with corrective tamping will result in losing control of the track quality as failures arise in a too quick pace. Some interviewees state that they are not familiar with a specific long-term strategy for planning tamping operations. In a discussion on the knowledge about steering documents there are some interviewees that claim they are not that versed with the context in BVF and BVH as they should be. However, most of the interviewees can describe the times during a year when they conduct tamping, whether it is a corrective or preventive tamping operation and what measurements that should be analysed to plan these operations. One interview person e.g. claims that the strategy used is the one that is stated in the contract i.e. to maintain a mean Q-value.

> *"Well, the strategy is probably just that the contractor should fulfil the demands in form of Q-value in the contract. I don't think we have any other strategy."- Maintenance manager within the Swedish Transport Administration*

Another person describes that they do not have a special strategy for operating tamping but that there is an ongoing discussion about tamping whole links at continuous intervals e.g. every third year. An alternative could be to tamp e.g. a third of the link every year instead. This issue will be further discussed in Section 4.1.4 .

There have been discussions about coordinating different maintenance measures and the efficiency of each measure. One interviewee states that there are problems with coordination of maintenance operations. This person describes that when tamping is conducted it is often preferable to perform other maintenance operations before, for example exchange of sleepers as this results in a new demand for tamping. Further, it is described that they have workweeks where different kind of maintenance operations is performed, such as replacement of rails or change of switches.

When questioned regarding the effectiveness of tamping some interviewees are of the opinion that tamping sometimes is performed at places where it has limited effect since the actual problem is something else. The opportunity to suggest alternative and sometimes more extensive measures is varying, depending on what costs are associated and the importance of the rail link. One of the interviewees claims that there are insufficient tools for analysing whether tamping will be effective or not.

4.1.2 Low margin in tenders

Railway tamping is not considered to be a very profitable business for a contractor. It has been discussed that the contractor has small margins in their budget, which makes them vulnerable for varying material costs since the contracts times are five years long. One interviewee claims that contractors from abroad have been surprised by low tenders here in Sweden.

Another interviewee points out that the profit becomes low for contractors if they do not manage to prioritize preventive measures in performance-based contracts. One of the economical incitements in this type of contract is to conduct preventive maintenance in order to minimize costs for corrective measures, which are expensive. It is crucial for the client to be strict on these economical questions e.g. not paying for corrective maintenance in order to maintain the power of this incitement. This is claimed to be a threshold for transitions from traditional to performance-based contracts – both for the client and the contractor.

> *"If we could describe our facility better and point out which problems we want to solve, then I think we could have better possibilities to increase the Q-value" - Maintenance manager within the Swedish Transport Administration*

The responsibility for planning tamping sections alternates depending on the contract form. Some of the interviewees are of the opinion that this division is not always followed, that the Swedish Transport Administration sometimes suggest a plan for tamping even though it lies under the responsibility of the contractor. According to the interviewee, this might undermine the division of responsibility in the contract. The reason that the agreed division is not followed can sometimes be that the contractor feels in need of help to identify sections for tamping or that the maintenance manager of the Swedish Transport Administration wants to ensure that tamping is carried out at the correct places.

4.1.3 Limitations with mean Q-value

There have been discussions about the use of Q-value in contracts. One issue is the distance over which the Q-value is calculated. Some contract uses a mean value for the whole link. This has lead to that section with a low Q-value can be compensated with a similar length section with a high Q-value. Since it is the mean Q-value that is the condition in the contract, the contractor does not have to take measures for the low-quality section.

Due to this issue, one interviewee asks for more control to conduct preventive tamping maintenance in the contract and claims that maintaining an average Q-value with these conditions may inhibit preventive maintenance. The goal is to maintain a good track geometry quality, not just a good mean Q-value. However, another interviewee explains that they have now divided the link, over which the mean Q-value is based on, into smaller sections. In this way, sections with a low mean Q-value will be easier to detect and set a functional demand for.

> *"Honestly, let's say if you have a demand on Q-value of 90 on a link, then the contractor don't want to have a Q-value of 100. Of course, you want to be as close to 90 as possible." – Maintenance manager within the Swedish Transport Administration*

"When we had a Q-value over a link, it could be so bad that some distances were really bad but the contractor still managed to hold the function by the mean value for the whole link." – Maintenance manager within the Swedish Transport Administration

Another issue that has been discussed is that the mean Q-value in the contract is based on an arbitrary judgement of the latest years' mean values. One interviewee asks the question why this particular limit is chosen and why it is not higher. The person discusses the possibility to have a demand in the performance-based contract to tamp a certain length every year to ensure a better standard and quality. Further, this person discusses that the Q-value is a good tool to describe the function demand in performance-based contracts. However, this is not per automatic the best method for keeping a high track geometry quality in the long run, to a low cost.

4.1.4 Difficulties to acquire possession time

A critical parameter for planning tamping is to acquire possession time. This issue is also pointed out by most of the interview persons as the main limiting factor concerning efficiency in the whole tamping process. The main concern is to get consistent possession times to get a high efficiency during one shift. One person claims that the possession time can vary between an half an hour as worst, and seven hours in the best case. The person also claims that the average efficiency for a shift is roughly about two hours running time with respect to start and end time. The time it takes to get a machine started on track and ready to tamp is estimated to 15-20 minutes for each possession time and about the same time to finish a work, i.e. getting the machine away from track.

The concept of continuous tamping is discussed during the interviews, by which is meant to perform tamping uninterrupted on longer sections instead of tamping several short sections. For example, 25% of the total track length could be tamped every four years, meaning that the whole link would be tamped with a return time of four years. Most of the interviewees are appealed by this concept, one of them stating that this would result in better economy and a better quality of the track. Another of them also thinks that continuous tamping would result in a possibility to extend the time intervals between tamping measures. Some of the interviewees approve of the concept but also stress that some sections would have to be tamped every year independently of continuous tamping.

Planning time in BUP and BAP differs between the contracts. One line is a single-track and requires total stop in traffic and the contractor normally applies for this in the long-term planning system, BAP. However, some interviewee claims that their applications are often turned down and instead they are offered shorter times that are similar to the times they would be offered if they would apply in BUP from the beginning. This is a problem for the contractor since they also have to book machines from another booking system a certain time in advance and these two systems should coincide. Another interview person claims that the tamping possession times are often down-prioritized due to e.g. extra trains. This person also describes that the contractor normally apply for possession time in BUP to be able to plan other types of maintenance work in conjunction with tamping.

Another problem regarding BAP-planning stated by one of the interviewees is the forward planning. Since track geometry quality change in time and is normally planned on basis of previous measurements within some weeks before the tamping action, it is difficult to evaluate which distances that should be tamped within the next 1,5 years. The availability of possession times depends on several parameters, e.g. it is more difficult on heavy trafficked lines compared low-traffic and it also depends on if it is a single- or a double track.

> *"We can not specify the projects, since we do not know exactly what maintenance operations are necessary in 1,5 years." - Maintenance manager within the Swedish Transport Administration*

4.1.5 Lack of follow-up methods

As stated in Section 4.1.1, none of the interviewee describes a clear strategy for evaluating tamping operations regarding the planning or the results but some of them can describe the measurements that are used to follow-up the contract. Regarding qualitative follow-up, one of the interviewees describes how the measurements that are performed in the autumn are normally used to evaluate if the contractor has fulfilled the goals regarding the Q-value. This evaluation is later presented at a meeting with the contractor and client.

> *"No, I cannot say that we have followed up how a single tamping operation actually improves the Q-value... No we have never looked at it in that way"- Maintenance manager within the Swedish Transport Administration*

One interviewee claims that the follow-up method is only performed in an economical point of view, ensuring that the ordered tamping sections have been delivered, but that no analysis is performed on whether the desired effects are achieved. Another interviewee expresses confidence that Optram will offer a simple method for follow-up, but has not yet the knowledge of how this follow-up is performed.

4.2 Present state description of Optram

This section will describe some obstacles in Optram that have been expressed by the interviewed persons regarding usability and the educational possibilities that have been offered the interviewed persons.

4.2.1 Optram's current usability

Usability for software can be defined as "*Extent to which a product can be used by specified users to achieve specified goals*" (International standard, 1998). This can be measured with parameters that describe effectiveness, efficiency and satisfaction.

A common explanation why the interview persons do not use Optram is because of lack of knowledge and experience from the program. The users are accustomed to the old system and describe the transition as a threshold. One PDF-user with some experience of Optram prefers PDF in the present situation since no settings have to be performed; it is just ready to use. One of the interviewees states that the data presented in Optram is too complex for a new user to understand. The result of this can be that the user is reluctant to use Optram and rather lets someone with more experience perform the task.

> *"Well, those analogue diagrams are more complete. It is more work in Optram to adjust the settings to the way I want it. There (in the analogue diagrams) you will get the right scales and everything at once." – Maintenance manager from a contractor*

One interviewee has experienced problems with print settings. The person claims that there are too many steps to get the same format and scale as for the analogue diagrams, which they are most familiar with. Further on, the more functions you add to the diagram the more difficult it is to make a good printout. Another comment is that the colours in Optram are too sharp and glitzy.

Some of the interviewees are asking for functions in Optram that are already available. An example of this is the trend analysis function, which can be used to identify sections with great changes. Some of those asking for the available functions are aware that they already exist but are calling for simpler functions.

4.2.2 Education possibilities

On the question whether the interview persons has been given education for Optram, there are some uncertain answers. Some claim that they have been offered education but then cancelled and other claims that they have been informed about Optram when it was released but then nothing has happened. Another person is still waiting for education and that Optram should be "ready to use" and a third person has been to an introduction course but claims that their contractor has not been given any courses but has learned some functions on their own. A more aggressive promotion for Optram i requested and one interviewee questioned the strategy to release a program while it was not complete and still had several bugs. This first impression of an unfinished program makes the users wait to use it until it is finished.

> *"I've got some information about this (Optram), three years ago that this project had started and that is the only information I've got. So, I have opened the program myself and tried to use it."- Maintenance manager within the Swedish Transport Administration*

One interviewee says that it is important that the maintenance managers at Swedish Transport Administration and the contractors are given an adequate education before the analogue system is shut down. It is also crucial to support the contractor so that they have someone to call in case they have problems with Optram.

4.3 Desired functions in Optram

The hopes for Optram to be a useful tool for planning tamping actions in the future are high. Planning tamping sections is a time-consuming operation and the biggest hope among the interview persons is that Optram should be able to suggest such a plan by itself. This section will describe some desired functions and visions for Optram that has been expressed during the interviews.

The most common hope for Optram has been that it can recommend the user which sections that should be tamped on a line by just pressing a button on the keyboard. Denmark has for example developed a system for analysing track geometry quality measurements from a recording car that can give suggestions of were tamping should be conducted.

> *It is not so easy to decide which sections that should be tamped. Or, I mean, it is easy to pick out sections, but the question is what is best for the track geometry quality? - Maintenance manager within the Swedish Transport Administration*

Other suggestions are that Optram should describe the demand of tamping in the same way as BIS works; there you can get pre-defined reports by choosing a certain link. Further, there is a desire to see a continuous degradation rate of Q-value. This is described to be useful for long-term planning but also to evaluate what effects single tamping operations could has for the track geometry quality.

There have been discussions about asking Optram pre-defined questions about which operations that should be conducted to increase the Q-value with for example five units over a certain link. The program should then give a proposal about where tamping should be performed to manage this and also give rough cost estimations. This type of function could be time-saving instead of going through kilometre by kilometre manually and the cost estimation can give a quick hint about the price level of such operations.

> *"It would be interesting to choose a link or section and ask Optram what measures that should be done to e.g. reach Q-value 90 if I have 85 today." - Maintenance manager within the Swedish Transport Administration*

Another suggestion is the other way around, that Optram should suggest tamping operations based on a certain amount of budget. It should then make a proposal based on a given budget, which is often a situation in the reality, about how this money can be spent in the most cost-efficient way. It will then give suggestions for the most prioritized sections.

5 Discussion and analysis

This chapter will analyse and discuss the results from the previous chapter. The analysis is conducted by comparing the interviewees' answers and discusses how the selected issues could be improved with suggestions of new functions in Optram. The sections are in the similar chronology as the results.

5.1 Improvement potential in the tamping process

Some issues in the tamping process that could be improved by developing Optram have been brought up in the results. These issues are further evaluated and are discussed in this section.

5.1.1 Lack of long-term strategy

On the question about what strategy the interview persons have in their contracts there is no one that clearly has pointed that there is a clear strategy for planning tamping operations. However, on other questions about how tamping is performed there have been clear descriptions given e.g. about how and when preventive and corrective maintenance is performed and the planning of it. In the handbook BVF 825.20, chapter 4 "Strategy for tamping of tracks and switches" there is a descriptive but general strategy stated with recommendations for planning, criteria for tamping and follow-up. However, it is possible that these persons have an own strategy kept in mind, based on these recommendations, but it is unclear how they correlate. This question is also related to the discussion about how well the client and contractor read BVF and BVH documents. Since some of the interview persons have claimed that they are not as versed as they could be in these documents, it is unclear whether the recommended strategy is applied in reality.

A common discussion about tamping strategy in general has been weather to tamp short sections where the track geometry is locally bad or to tamp longer connective sections e.g. in continuous intervals. These possibilities are varying after traffic and depend on more circumstances than setting a certain strategy but still, there does not seem to be a clear pointed out strategy for all regions. Another circumstance is which type of contract that is applied. The strategy in a traditional contract should be managed by the client but in a performance-based contract it is more up to the contractor to set his own strategy for planning and tamping. However, this should be based on what strategy the client wants to achieve and can be challenging to formulate in a performance-based contract. In any case, is not obvious for any of the interview persons what strategy is, or should be, applied for tamping maintenance.

The quality of a long-term strategy is dependent on the knowledge of track geometry quality degradation and what effects tamping operations will give. This knowledge could help to optimise tamping operations and make it easier to coordinate with other maintenance operations. There is no analysis tool in the current situation that can be used for this purpose in the maintenance managers' and contractors' daily work. This makes it difficult to define long-term strategies. However, this is a potential area that could be improved by developing a tool in Optram that can make a prognosis of the track geometry quality degradation and tamping effects. This tool is further exemplified in Section 6.2.

5.1.2 Low margins in tender

Changing from a traditional contract to performance-based contract is a challenge for both client and contractor. The contractor has a larger uncertainty in the tender. From setting unit prices on given objects to calculate costs for preventive and corrective maintenance based on the current track geometry quality.

It is difficult to analyse the contractor's profitability without any insight in their budget. Basing this argument on discussions with clients will not guarantee objectivity of the interviewees. The contractor has an interest in giving a picture that their profit is low in this business in order to raise the tenders. This could have an effect on the client's view and it is also in his interest to say that the margins are small in order to get more capital for the next year's budget. However, the threshold that is described when entering a performance-based contract is crucial to overcome and this may be one the reason why the profit is considered as too low for the contractor. It should also be kept in mind that tamping is one part of a maintenance contract and it is possible that some parts in a contract are more profitable than others.

It is crucial for contracts that spans over a long time to have the possibility to make long-term plans in order to calculate a tender. Estimations of how the track geometry quality will change over time and what effect tamping will have, are essential parameters to evaluate the tamping demand. The relationship between preventive and corrective maintenance would be valuable to visualise with a scenario tool in order to increase the effects.

5.1.3 Limitations with mean Q-value

The Q-value is a useful tool to describe the function in a performance based contract since it is easy to measure and control. Normally, there is a measurement conducted before and after a tamping operation and it is therefore easy to compare the result and see the effect. Calculating a mean Q-value over a link could be useful for a rough quality estimation to compare links with each other or to get an idea about the budget. However, it is too blunt to be the basis for a contract. It is more appropriate to divide the link into smaller sections in order to get more control and detect quality disperses.

It is important to discuss the effects of basing performance-based contracts on a specific mean Q-value. It should preferably not be the only parameter that is evaluated since there are other parameters that can describe track geometry quality. Developing a prognosis tool in Optram could make it possible to find other types of parameters that can describe track geometry quality, in addition to the Q-value.

It is crucial for track geometry quality to set an appropriate Q-value limit that should be maintained. This requires knowledge about track geometry quality degradation and the effect of tamping measures in order to find an optimal limit.

5.1.4 Difficulties to acquire possession time

Allocation of resources that is necessary to perform tamping, is generally a question for the contractor, independent of whether the contract is performance-based or traditional. The reservation of possession time in BAP or BUP is however closely linked to the Swedish Transport Administration, where the planning of BAP and BUP is performed. In short, the system for reservation of possession time becomes an area where the performance of the contractor is depending on the decisions of the Swedish Transport Administration.

In the result from the interviews it is stated that insufficient priority is given to track maintenance, instead more trains are inserted in the time table. This is of course the perspective of persons responsible for the quality of the track; a person within a train transport company might say that too much time is reserved for track maintenance. On the other hand, track maintenance is unarguably necessary and if it is not carried out in a proper way it will result in other types of problems for train transport companies, e.g. speed limitations and possible suspension of track sections.

The main problem identified within the interview result is that there have been cases where the contractors experience that they are trying to reserve possession time long in advance but are denied due to priorities within the Swedish Transport Administration and thereby are prevented to achieve a long term plan.

It is also possible that the contractors have given an insufficient motivation in the application for why the desired possession time is needed. If performed tamping operations are not resulting in a fulfilled Q-value goal, the issue about lack of possession time can be brought up by the contractor as a way of putting the blame on the client. The process of applying for possession time and what is required of the application has to be clear so that there is a higher predictability in whether the contractors will have their applications approved or denied.

The lack of long term planning may also be a factor complicating the acquisition of possession time. By formulating a strategy in a more clear way further attention may be given as a spin-off effect to the importance of possession time in enabling efficient tamping maintenance.

5.1.5 Lack of follow-up methods

A selection of the regulations formulated regarding follow-up has been presented in the theory section and even though the regulations are not entirely clear the result of the interviews shows that follow-up is made, although the methods vary between the interviewees.

One clear pattern has been that the change of the Q-value produced by tamping is followed up in a greater extent on rail links where the contract documents formulate clear goals regarding q-value. This normally occurred in a performance based contract but also in some of the traditional contracts. The quality follow-up in the remaining contracts seem to be a bit more arbitrary, even though it can be argued that follow-up is even more necessary there as the client in those contracts normally is responsible for planning tamping sections and therefore will benefit from the experience gained from follow-up.

In the theory section the quality list is described as a possible tool for evaluation, however none of the interviewees refer to this tool when they were asked about methods for qualitative follow-up. The quality list shows the average Q-value over each kilometre and over longer inter-station sections. It is not possible to see how the Q-value has increased over the tamped sections, only how the tamping sections together have contributed to a better Q-value. This becomes a problem when communicating the effectiveness of the conducted tamping and might be a reason why the quality list is not used.

A more structured quality follow-up could have the benefit that the relation between tamping cost, amount of tamping operations and actual quality improvement would be more visualized. This relation can in turn be a useful tool for planning new tamping sections and identifying long-term tamping demand.

5.2 Evaluation of Optram's present state

The description of current usability of Optram points out interesting comments, which will be further discussed in this section.

5.2.1 Optram's current usability

The result of this study has shown that few of the assumed Optram users actually use Optram. Most of them prefer having measurement data presented in PDF-form. Even though the interview group is a very small part of the whole potential Optram user group, it is still notable that Optram is so sparsely used. Acceptance can be a problem with introduction of new systems and tools. If the tool is not accepted by the intended users, there is a risk that it will not be used as long as other more accepted tools are available.

The comments regarding Optram presented in the result are describing the software as complicated that requires several manual settings, which make it inefficient and presenting a user interface which is not making the users confident. An often discussed term regarding how well software is performing what it is intended to is user friendliness, or usability as it is denoted in a broader research context.

When evaluating the comments in the context of usability, it cannot be excluded that usability problems are contributing to the limited use of Optram. However, as few of the interviewees actually use Optram at all, it is not certain that usability is the main problem. Many of the remarks on Optram use have covered other shortcomings. It could also be question of attitude problems, were the transition from analogue to digital systems requires changes in the daily routines.

Two general and reoccurring remarks are that Optram has a too complex level of detail and that it requires previous experience of the user. Optram has been introduced as an expert analysis tool, why high detail level is an important feature, but in the context of budget planning and contract formulation there might be a need for a simpler tool, easy to understand also for someone not being an expert on track geometry quality.

Some examples of how this usability could be improved are declared in Section 6.3.

5.2.2 Education possibilities

Among the reasons why the interviewees are not using Optram, a common explanation is lack of education. According to the interviewees, they have been offered education but not in a sufficient extent. The support given to contractors in the form of education and error support is also stated as too limited. At the same time, some of the interviewees have stated that education has been available but they have turned down the given offers. It can be discussed who is to blame that insufficient education has been given to many of the users, but the problem that the intended users lack the necessary knowledge regarding Optram remains. When it comes to education, the amount of education is not the only thing that matters but also the educational method.

5.3 Desired functions in Optram

The suggestions from the interviews have mainly concerned introducing an advising tool in Optram, helping the tamping planners either to achieve a given Q-value with minimum resources or achieving a maximum Q-value with given budget. It would be possible to create a tool combining the two advising functions, see the example described in Chapter 6. The analysis of where to perform tamping to achieve the best result is time demanding and complex. An advising tool would simplify this analysis. Ideally, there should be enough time available to enable this analysis, but obstacles such as e.g. delayed delivery of measurement results or sudden changes in available budget, possession time or machines can imply that a less thorough analysis has to be made.

However, there is a risk with making these evaluations simpler and making them too simple. Optram's graphical view contains a large amount of data that can be overwhelming, but this data is basically raw, which minimizes margins of error. Advanced calculation programs that gives a specific output from a so called a "black box" with hidden calculations, gives the less-experienced user no chance to understand what happens with input data. Since the consequences from a bad track geometry quality can be serious, it is important to analyse such system from a safety view and control it with a parallel system in the beginning.

When looking at the composition of problems in the tamping maintenance process, as described earlier in this section, many of the problems seem associated to lack of long-term planning, directly or indirectly. Introducing a tool for prognostication of changes in track geometry quality would help for development and evaluation of a long-term plan. Positive effects of better long-term planning could also be improved follow-up and acquisition of better possession times. It is nevertheless important to point out that developing a tool for track geometry quality prognosis will not alone be sufficient to improve long-term planning. The tool will only have the ability to estimate whether a certain goal will be fulfilled or not, it is up to the organisation of the Swedish Transport Administration to formulate the goals and enabling their fulfilment by providing a realistic budget.

Several interview persons have described the obstacles with going from analogue system to Optram as many small thresholds. The layout is different and several settings have to be changed before it is ready to use. This might be an issue only for the beginners how are not familiar with the program and lacks education. However, these obstacles could be fixed with small measures, which can have a large effect on usability, especially for the beginners. Many small obstacles can disturb the overall impression and be large together and the first sight of software's layout is important in an introduction phase to a new program.

6 Recommendation of new functions in Optram

This chapter will present how the identified potential areas for improvement could be developed in Optram. The examples have been developed by the authors with the intention that they should be possible to internalize in the Optram software. The statistical data needed for the example functions is to a majority already available in Optram, so the question is more about presentation. Common for all functions is that the focus should be on usability and creating simple tools that can develop Optram as a decision support.

6.1 Tamping Recommendation Model

There is a desire for a function that can give recommendations for sections where tamping is needed. The input example data e.g. about cost estimations in this section is based on estimations from an experienced Maintenance Manager[7].

Recommended user group

The user group for this function depends on the function's accuracy. For planning certain tamping sections it is important to deliver high quality information about the planned sections to the manager of the tamping machine. This requires control and comparison of the function with current analysis methods to ensure that the quality is enough for this purpose. However, even with less accuracy, this function can anticipate were it is most likely that tamping will be required and give a rough estimation on what costs that can be expected. This can be a valuable tool for long-term planning and as a decision support to budget managers. The economical input in the second function can be used to estimate which sections that should be prioritized if an extra amount of money is given to the budget.

This example function, Tamping Recommendation Model, could be managed with two different alternatives that could be formulated as the following questions:

Alternative 1

Which sections for a certain position (input) is under a chosen Q-value (input) and what will the cost be for tamping these sections?

- E.g. the total distance for the chosen link with 60<Q<80 is 6 000 m, which is 17% of the total length of the investigated line. The recommended tamping positions are 432+400 to 435+000, etcetera and are prioritized after their mean Q-value. The estimated costs for this is 290 000 SEK and the mean Q-value for the whole link is estimated to increase from 75 to 85.

Alternative 2

Which sections for a certain position (input) should be prioritized to tamp for a certain budget (input)?

- E.g. a budget of 100 000 SEK can be used to tamp 1 250 m, which is 4% of the investigated link. The recommended sections that should be prioritized are 432+400-433+000, etcetera and the mean Q-value is estimated to increase from 75 to 79 after measures.

[7] Jack Hansen, Project leader, Swedish Transport Administration. Interview 2012-03-27

The output will show recommended tamping sections with length and an intern prioritizing list based on mean Q-value for the selected section. Moreover, the total length is declared with a current mean Q-value and estimated change after conducting the recommendations sections. Estimation of costs can be based on a default average tamping price per meter that can be adjusted by the user. The default settings are that tamping costs 40 SEK/m and that costs for establishment are 50 000 per link. The increase in Q-value units after a conducted tamping operation can also be changed as an option. The standard value is set to +10 units per taming. An illustration of the functions is showed in Figure 6.1.

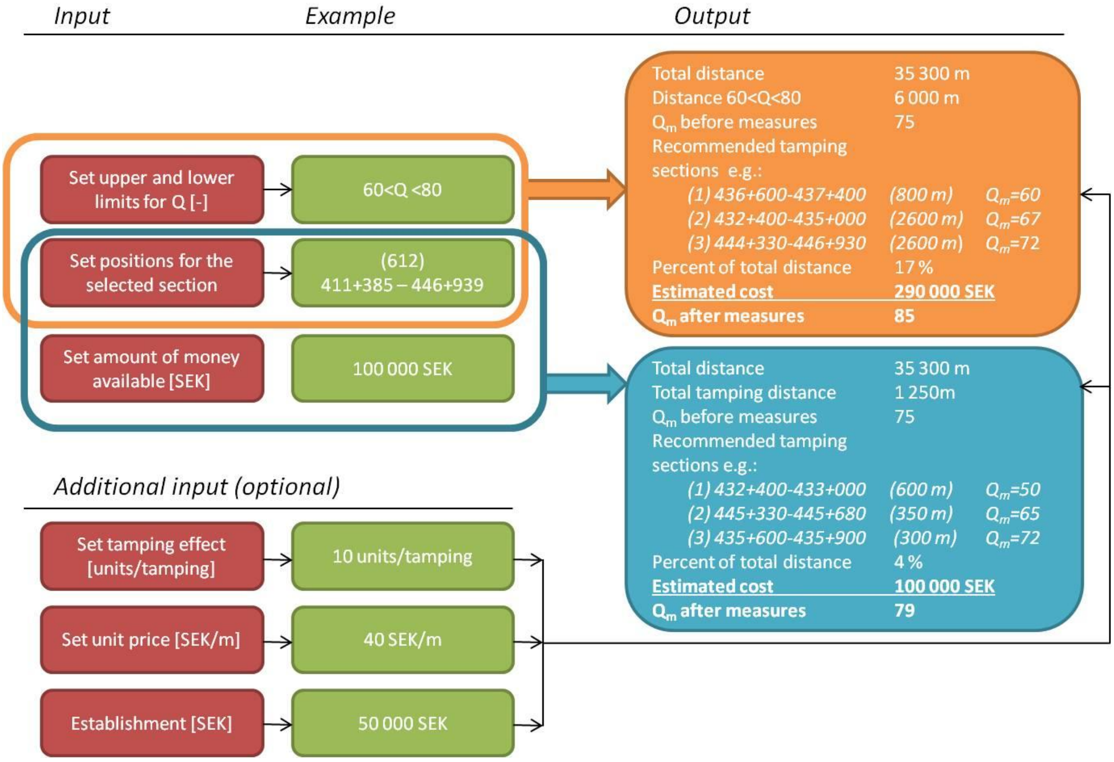


Figure 6.1 Illustration of how the Tamping Recommendation Model could be managed. There are two input alternatives. The orange boxes require an input of Q-value intervals that should be tamped and the blue box alternative requires an input of available budget. Recommended tamping sections are prioritized and denoted before the position. As an option, it is possible to adjust unit price and establishment costs. Mean Q-value is denoted as Q_m.

Limitations with the model

Conducting tamping on the recommended sections with e.g. Q<80 does not per automatic mean that the quality will rise to Q>80. The assumption is that a tamping measure will increase the Q-value with 10 units but this value can vary in reality. It is difficult to estimate the effect of a tamping measure and a further analysis, based on statistical data, is necessary to ensure a high accuracy.

Sections with a very low Q-value might require other type of maintenance measures. That is why a lower limit for the Q-value is set as an option, to sort out these sections e.g. sections with a Q-value below 60 should be noted with a warning sign. This model should be used for the line in a link i.e. no switches or crossings are considered due to its complexity. However, recommended sections by the model could require other types of measures than tamping e.g. if the track is worn or if an insulated bar should be replaced.

Tamping costs will vary depending on how long the recommended sections are and possession time on the link. It could be possible to set a limit for shortest recommended section that should be suggested and instead recommend another type of measure e.g. with a tractor. The price could also be adjusted for different length intervals e.g. the price for a section length larger than 2 000 m could be lower than for a lengths between 500-1 000 m. This is however, not always regulated by the client in contracts either.

6.2 TGQ Degradation Model

Long-term planning of larger tamping operations require that the track can be left without tamping for a couple of years, so it is of great importance that the tamping planners can be certain that the rail link will meet the target quality level for a couple of years without performing further tamping operations in the meantime. This certainty is difficult to establish with the tools presently available, which is the reason why a Track Geometry Quality (TGQ) Degradation Model could improve the decision support for tamping.

Recommended user group

The TGQ Degradation Model is intended to help maintenance managers and contractors in their long-term planning of tamping, here the model will aid in optimizing the available resources. By enabling improved long-term planning the acquisition of possession time will also be simplified, possibly resulting in longer connective possession time and reduced cost for maintenance.

Further, the TGQ Degradation Model can aid the client in the formulation of traditional contracts. By simulating the consequences of different amounts of tamping operation resources, a suitable level of tamping operations can be set in the contract. The TGQ Degradation Model can also improve performance based contracts, by giving the contractor an improved possibility to analyze the future tamping demand and thereby reducing the risk of the contractor.

The example below, along with Figure 6.2, shows how this model could work.

Step 1

What is the present state of the rail link (input) in terms of Q-value and Q-value degradation rate?

- The investigated rail link has a total length of roughly 35 km and the present mean Q-value (Q_m) over each 100 m section is calculated and sorted into five intervals, in this case below Q-value 60, 60-70, 70-80, 80-90 and above Q-value 90. The intervals are plotted in a graph and the mean Q-value over the whole rail link is also calculated.
- The Q-value degradation rate is calculated as a mean over the same 100 m sections, after which the sections are sorted into degradation rate intervals, in this example is chosen 0-8 Q/year as normal value (See Table 3.2) and >8 Q/year as increased degradation rate.
- By evaluation of the present Q-value and the corresponding Q-value degradation rate for each of the 100 m sections, a general scenario can be formulated on how the total mean Q-value over the rail link will develop over the next few years.

Step 2

Based on the general scenario of the rail link and given the target mean Q-value (input), what consequences will the chosen amount of tamping for this year have for the mean Q-value over the rail link during the next two years?

- If the worst 10% of the rail link is tamped this year, the mean Q-value will be sufficient in the end of the year (81) but will require additional tamping operations next year.
- If the worst 20% of the rail link is tamped this year, the mean Q-value will be sufficient in the end of the year (83) but the value of 2013 will still not be sufficient with certainty (79), further tamping will be required the next year.
- If the worst 35% of the rail link is tamped this year, the mean Q-value will be sufficient both this year (86) and during 2013 (82), allowing that no tamping operations are conducted the following year and focus can instead be put on planning a larger tamping operation in two years.

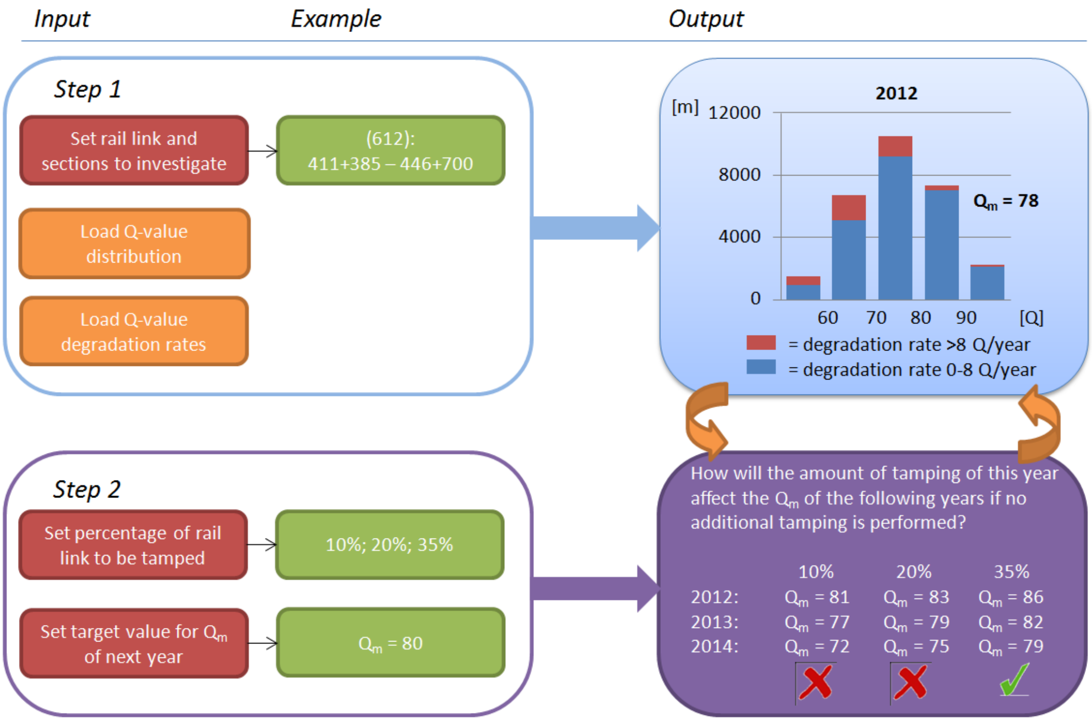


Figure 6.2 Illustration of how the TGQ Degradation Model could function. The model is used in two steps, first for analysis of Q-value distribution and Q-value degradation and secondly for estimation of consequences for tamping operations. The amount of tamping performed for the present year can be adjusted iteratively until the desired prognosis is achieved.

Step 1 of the TGQ degradation model can further be used to make a prognosis of the Q-value development if no tamping is performed.

Limitations with the model

Creating an accurate model for track geometry quality degradation is very complex. Factors such as geotechnics, facility age and track geometry will create a characteristic for each rail link, so the statistical data used must originate from the rail link in question. Moreover, the accumulated load can have an impact on the rate of degradation. Therefore it is important that the model is developed to also take traffic data and local physical conditions into account. The effect of tamping operations is also difficult to foresee, statistics regarding the effect will prove a probable but not totally reliable solution. Independently of the quality of the used data, there will still be uncertainties and therefore it is important that the level of probability for the prognosis made is known.

This thesis is limited to maintenance operations with tamping. However, a low Q-value could require other type of maintenance operations. These are not considered in this model. Further, only lines in the links are considered, i.e. no switches or crossings.

The TGQ Degradation Model will help to improve preventive tamping, but the corrective tamping operations will remain. It is possible that the model could be developed to better show the relation between the mean Q-value over the rail link and the amount of reported C-faults. This is however not included in the present example.

Introducing a new simplifying model can also have backsides. For example, by presenting a simplified truth there is a greater risk that valuable information is missed. Depending on if the prognosis tool is a supplement provided in Optram or if it is presented independently, this will probably have effects on in what extent Optram is used and if the prognosis tool thereby will have the effect of increasing or decreasing the knowledge about Optram and measured data.

6.3 Examples of how to increase the usability in Optram

This section will give suggestions on one new drawing tool and two smaller adjustments in Optram that can increase the usability. These suggestions are based on interviews of users that have some kind of experience from Optram.

Drawing tool for suggested tamping distances

To increase the efficiency of Optram in communication it could be useful with a possibility to mark suggestions of tamping sections directly in the program. The function can be compared with the possibility to draw with a marker in a PDF-print out. The distance of each section should automatically be calculated and visualised next to the marker. See an illustrative example in Figure 6.3. These marks can be saved as a layer and sent to the person on a tamper machine or e.g. to another person for review. It should be possible for the next person to make comments or redraw new distances in order to communicate. This can be compared to how the function Comments in Microsoft Word works. There you can e.g. mark a piece of text and comment it and then send it to a colleague that can revise these comments and send it back again. The original editor can then accept or reject changes.

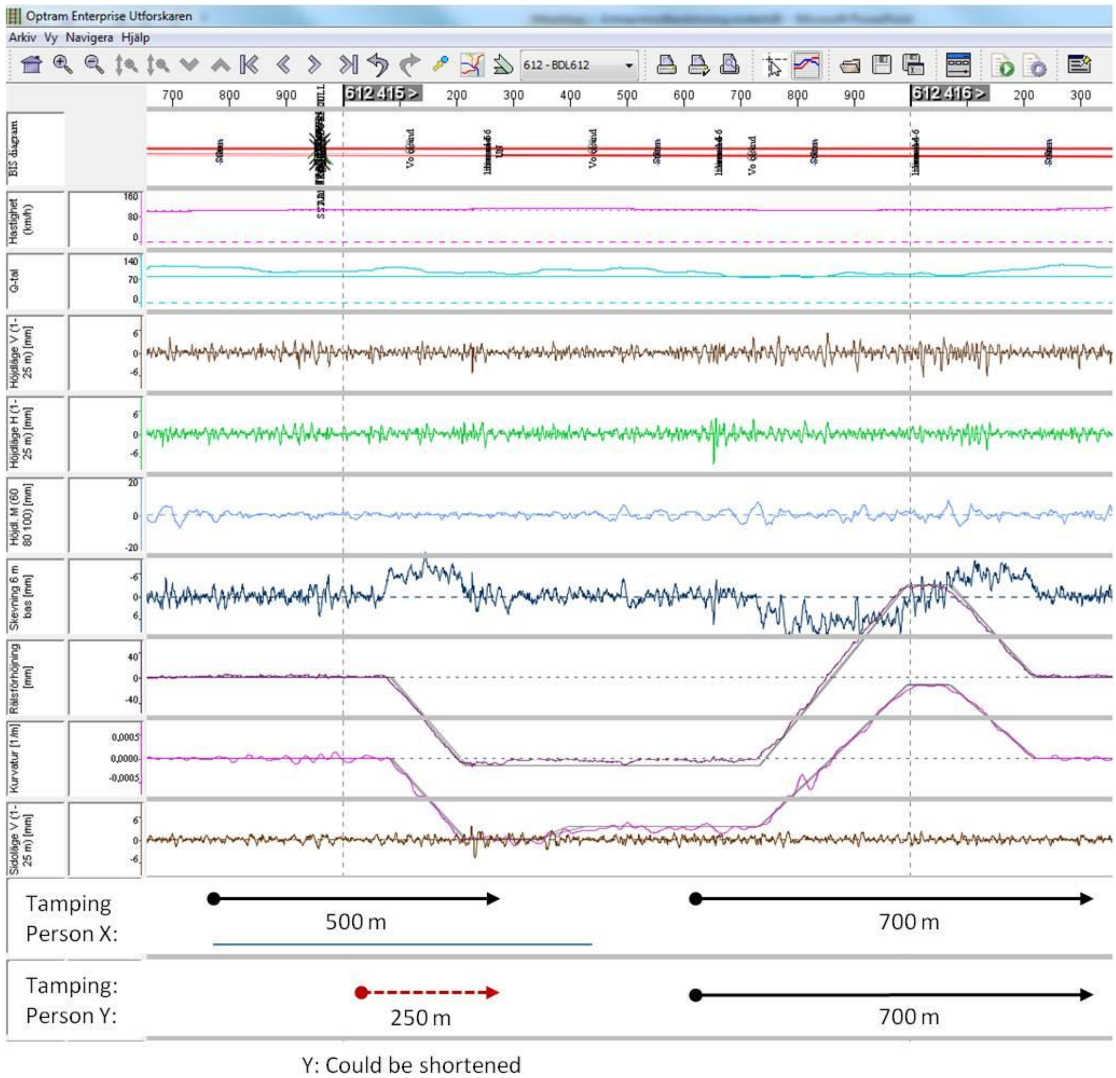


Figure 6.3 Illustration of how a drawing tool can be managed in Optram. Persons can communicate with comments and mark with a drawing tool, ther suggestion of tamping measures.

The input data from the drawing tool could be exported to Excel with information about the link and the recommended tamping distances with their lengths. An additional “check-box” could be added in a column next to the tamping sections. When tamping is performed, the box will be checked and these sections could be exported directly to BIS.

This function could simplify communication with the project leader and the tamping machine manager.

Change default scale to 1:5000

The default scale in Optram is 1:19500, which is smaller than in the analogue TGQ-diagram that is 1:5000. It is difficult to distinguish specific data and make some kind of evaluation with this setting. A typical user that evaluates the track geometry quality and plan tamping will have to enlarge the scale to make it useful. It would therefore be recommended to change the default scale in Optram to the same scale as in the analogue diagrams, which is 1:5000.

Simplify print settings for additional functions

Default print settings for the scale in Optram are the same as the scale for the current opened window. The tricky part is when additional functions are inserted into e.g. C-faults, since they will appear alone on a separate page. This could be edited by the user itself be replacing functions and adding a new position scale and rearrange all functions in a desired way. However, this could be simplified by setting a few different suggestions of functions that are arranged in a printer-friendly way that will fit on one page or automatically add the positions to this separate page.

7 Reflection

The goal with this thesis has been analyse Optram's improvement potential for the tamping maintenance process and to suggest new improvements with purpose to improve the decision support. This chapter will discuss whether this goal has been reached and how methodology and delimitations have affected the outcomes of the thesis.

The methodology has mainly consisted of a literature study and qualitative interviews, which have been the basis to understand the tamping maintenance process. The Swedish Transport Administration is a large organisation with a lot of experience and knowledge within the personnel. Several steps within the tamping process are based on this experience but have not been clearly documented in an accessible way. The working process of this thesis has therefore put more effort and time than expected to get the picture of how tamping is carried out today. Qualitative interviews have been a good method for this purpose as they have given both the opportunity to collect a result and to improve the authors' knowledge so that the interview manuscript could be refined during the interview process. One limitation with the chosen interview methodology is that few persons have been interviewed. This could be have been complemented by more interviews or some type of questionnaire with a larger interview group.

The uncertainty within the thesis could be discussed due to this limited numbers of interviewed persons. By choosing interviewees with a geographical dispersion, experience from different contractors and coming from both traditional and performance-based contracts, it has been attempted to achieve a more broad perspective. The regional differences were expected to be larger than they actually were. Six interviews have been considered to be enough material for the results. However, five of these persons were from the Swedish Transport Administration and one was a contractor. It would have been interesting to perform one or two additional interviews with a contractor. This could have influenced on the results but since performance-based contracts have not been in use for so long time, there is limited experience of Optram among the contractors.

In the presentation of the result and the discussion chapters, a number of issues have been selected from the interview result for further study. This selection was based on the occurrence of the issues in the interview result as well as a judgement by the authors. It is possible that there are other issues equally important for the development of Optram that has not been identified in the thesis work. A larger interview group or better knowledge on beforehand from the authors might have reduced this risk. However, a great number of issues were sorted away to make the interview result manageable. Further important issues would have required an extended study and might not have been practicable within this thesis.

The exemplifying suggestions for new functions in Optram are based on inputs from the interviews, supported with the writer's creativity. These are realistic suggestions that could be used as a draft for further development. However, it is important to keep in mind that this type of examples are simplified and that there are many other influencing factors in reality, which should be taken into account while working with these tools. New functions should be analysed in a usability perspective in order to create a function for both client and contractor. It is a challenge to make these mathematical functions in Optram usable for persons without expertise knowledge.

Among the limitations decided upon initially in the thesis work, it has gradually been clear that one of them has a great impact on the tamping maintenance process, namely that the study would not consider other maintenance work than tamping. Other types of maintenance operations have to compete for the available possession time and therefore it is natural that other types of maintenance operations has an impact on what tamping operations can be performed. It would be interesting to further study how better coordinated maintenance planning can improve the tamping maintenance process and railway maintenance as a whole.

Railway maintenance is an up-to-date subject in media and track geometry quality is an important factor that affects the degradation rate for other facilities in the railway although it might not be obvious. Development of better analysis tools to perform tamping can have a positive effect on other maintenance operations. Further, Optram can analyse other functions than track geometry quality, such as overhead lines. This connection could be further developed in order to develop the coordination between different maintenance operations. International aspects have been limited in this thesis due to its magnitude, but it is interesting to keep the development work of Optram updated with international experience. It could be interesting for Sweden to cooperate more international in these types of questions.

This thesis has recommended two types of new functions and some improvement suggestions for Optram. The response from the supervisors at the Swedish Transport Administration has been positive so far and could be possible to further develop these new recommended functions. One of the minor suggestions i.e. to change the default scale is already conducted. The thesis purpose, to improve Optram as a decision support is an ongoing progress. This work has contributed to that development by listening to the software's user group and connecting their suggestions to an improvement potential in the tamping process and suggest new functions. Hopefully, this will contribute to the development of Optram.

7.1 Recommendation of further studies

The development of Optram is an ongoing work at the Swedish Transport Administration. However, the goals with this thesis is to identify Optram's improvement potential and how it can be developed, which are questions that needs a deeper understanding about the tamping process and the users' opinions.

To enable a further improvement of Optram and the tamping maintenance process, the authors have identified subjects for future studies and recommend that following topics are studied based on the outcomes of this thesis:

- *To perform a usability analysis of Optram with a larger group of Optram users, studying user related issues pointed out in this thesis.*
- *To further develop the suggestions in this thesis about the Tamping Recommendation Model and the TGQ Degradation model, making them more applicable by increasing the number of factors taken into account.*
- *To study how different types of maintenance operations could be planned in a more cooperating way and how this would affect the tamping maintenance process.*
- *To perform an international benchmarking study of how track geometry quality is evaluated.*

8 Conclusion

There is a development potential for Optram in order to improve the decision support for tamping maintenance. This thesis has identified the following issues in the tamping maintenance process that could be improved:

- *Decision support for short- and long-term planning*
- *Possibilities for contractors to calculate on tenders in performance-based contracts*
- *Using Q-value as an indicator of the contractor's performance in performance-based contracts*
- *Acquiring possession time for tamping operations*
- *Follow-up routines after tamping operations*

Optram's current usability could be improved with smaller measures in the current default settings in order to increase the user's satisfaction and efficiency such as changing scales and introducing a drawing tool. However, in order to improve the identified issues there is a desire for new functions. This thesis exemplifies two functions that have potential to improve the identified issues by being able to:

- *Recommend tamping sections based on Q-limits or by an available budget for short-term planning of tamping maintenance*
- *Perform degradation prognosis of track geometry quality for long-term planning of tamping maintenance*

The examples are based on simple assumptions and calculations which will provide rough, but easy-understandable answers for decision makers. Further development of Optram by communicating this mathematical and statistical tool with pedagogical methods into a program with high usability is recommended.

9 References

Andersson, Evert and Berg, Mats. 2001. *Järnvägssystem och spårfordon. Del 1: Järnvägssystem.* Stockholm : Järnvägsgruppen KTH, 2001.

Banverket. 1997. *BVF 587.02 Spårlägeskontroll och kvalitetsnormer.* : Banverket, 1997.

—. 1995. *BVF586.10 Skarvfritt spår.* s.l. : Banverket, 1995.

—. 2004. *BVH 825.20 Riktning av spår och spårväxlar.* : Banverket, 2004.

—. 2009. EB Botniabanan. *EB Drift och underhåll av järnvägsanläggning Botniabanan.* : Banverket.

—. 2009. *Entreprenadbeskrivning - Avseende drift och underhåll av järnvägsanläggning: Botniabanan..* : Banverket, 2009.

Corshammar, Pelle. 2006. *Perfect Track.* Lund : 2006.

—. 2008. *Perfekt Spårgeometri: Framtidens spår.* Lund : 2008.

Esveld, Coenraad. 2001. *Modern Railway Track.* Zaltbommel : MRT-Productions, 2001.

International standard. 1998. *Ergonomic requirements for office work with visual display terminals - Part 11 Guidance on usability.*: International standard, 1998. ISO 9241-11.

Matisa. 2012. MATISA Matériel Industriel S.A. *MATISA Matériel Industriel S.A. - Tampers.* [Online] 2012. [Cited: 24 April 2012.] http://matisa.com/matisa_ang/matisa_b45.html.

Näringsdepartementet. 2011. Järnväg. *Regeringskansliet* . [Online] Oktober 2011. [Cited: 02 05 2012.] http://www.regeringen.se.

Ryen, Anne and Torhell, Sven-Erik. 2004. *Kvalitativ intervju: från vetenskapsteori till fältstudier.* Malmö : Liber Ekonomi, 2004. ISBN 9147072784.

Trafikverket. 2011. Intranät. *Trafikverket.* [Online] 11 28, 2011. [Cited: 03 20, 2012.] intranat.trafikverket.local.

—. 2010. *Solkurvor - en allvarlig störning.*: Trafikverket, 2010.

UIC. 2010. *Monitoring Track Condition.*: International Union of Railways, 2010.

Appendix I – Interview manuscript

Intervjupersonen

- Vad har du för arbetsbefattning?
- På vilket sätt kommer du i kontakt med spårriktning?
- Vad för typ av kontrakt gällande spårriktning arbetar du i idag?
- Funktions- eller utförandeentreprenad?
- Hur länge har du arbetat med spårriktning?
- Planerar du spårriktningssträckor?

Generella frågor

- Hur upplever du att spårriktning fungerar idag?
- Är det tillfredsställande kvalitet på spåren inom din region idag?
- Hur upplever du relationen till entreprenören?
- Hur ser/vill du att spårriktningen har utvecklats om 5 resp 10 år?

Målrelaterade frågor

- Hur skulle du beskriva den strategi som används för spårriktning på din bandel?
- Arbetar man i spårriktningsplaneringen mot bestämda mål? I så fall, vilka är dessa?
- Utförs spårriktning vid behov eller med jämna tidsintervaller?
- Används andra kvalitetsmått än K- och Q-tal för att mäta tillståndet på din bana?
- Hur upplever du att gällande standarder och riktlinjer fungerar idag?
- Hur ofta läser du BVF:er och andra hjälpande dokument?
- Känner du dig väl informerad om vad som står i BVF:erna
- Upplever du att dessa är enkla att förstå?
- Går de att tillämpa till punkt och pricka i verkligheten?
- Saknar du riktlinjer?

Förfrågningsunderlag

- Hur upplever du kvaliteten är idag på förfrågningsunderlaget?
- Får du synpunkter från entreprenören om kvalitet på förfrågningsunderlagen?

Utvärdering av mätdata

- I vilken utsträckning analyserar du mätdata?
- Hur ofta använder du analog PDF-mätdata från spårlägesmätningar i ditt arbete?
- När du tittar på analog mätdata som PDF, vilka faktorer bedömer du som viktigast att utvärdera för att avgöra spårriktningsbehov?
- Hur prioriterar du bland de uppmätta parametrarna? (dvs av Q-tal, höjdläge, skevning… etc)
- Använder du ytterligare data för att planera spårriktning och i så fall vad?
- Används B-och C-felslista?
- Används BIS-data eller BESSY?
- Används annan typ av underlag?
- Hur ofta använder du Optram?
- Använder du Optram i större utsträckning än PDF-filerna?
- Om inte, varför?

- När du tittar på mätdata i Optram, vilka faktorer bedömer du som viktigast att utvärdera för att avgöra spårriktningsbehov?
- Vilka funktioner använder du i Optram?
- Använder du inställningsfiler?
- Sparar du egna inställningsfiler?
- Vilka ytterligare funktioner önskar du i Optram?
- Vart vänder du dig om du behöver hjälp med Optram?

Planering av åtgärder

- I vilken utsträckning är du med och tar beslut om vilka sträckor som ska spårriktas?
- Är det så det är tänkt att fungera enligt kontrakt?
- Om inte, görs någon form av ekonomisk kompensation för förändringen?
- Upplever du att det finns begränsningar, tidsmässiga eller ekonomiska, som avgör hur stor del av spårlägesfelen som kan åtgärdas?
- Skulle ni spårrikta längre sammanhängande sträckor om det fanns utrymme för det?
- Använder du någon värderingsmetod för att avgöra om en punktfel ligger inom tillräcklig närhet till en planerad åtgärd för att inkludera den?
- Upplever du denna avvägning som vanligt förekommande?
- Upplever du att det finns riktlinjer att följa?

Utförande

- I vilken utsträckning upplever du att alternativa åtgärder används för att avhjälpa återkommande fel? Exempelvis slipersbyte, rälbyte, byte av växlar och plankorsningar, byte av trummor eller ballastrening?
- Finns det ett behov av att utveckla denna arbetsmetodik?
- Om det inte utförs, beror det på ekonomiska faktorer eller beror det på tillgängliga tider?
- Vilken kapacitet har de spårriktningsmaskiner som används på din bandel?
- Är det önskvärt att använda maskiner med högre kapacitet?
- Varför/Varför inte?
- Hur upplever du att effektiviteten spårmeter per timme respektive effektiva timmar per skift är vid spårriktning?
- Hur tror du att denna effektivitet kan förbättras?

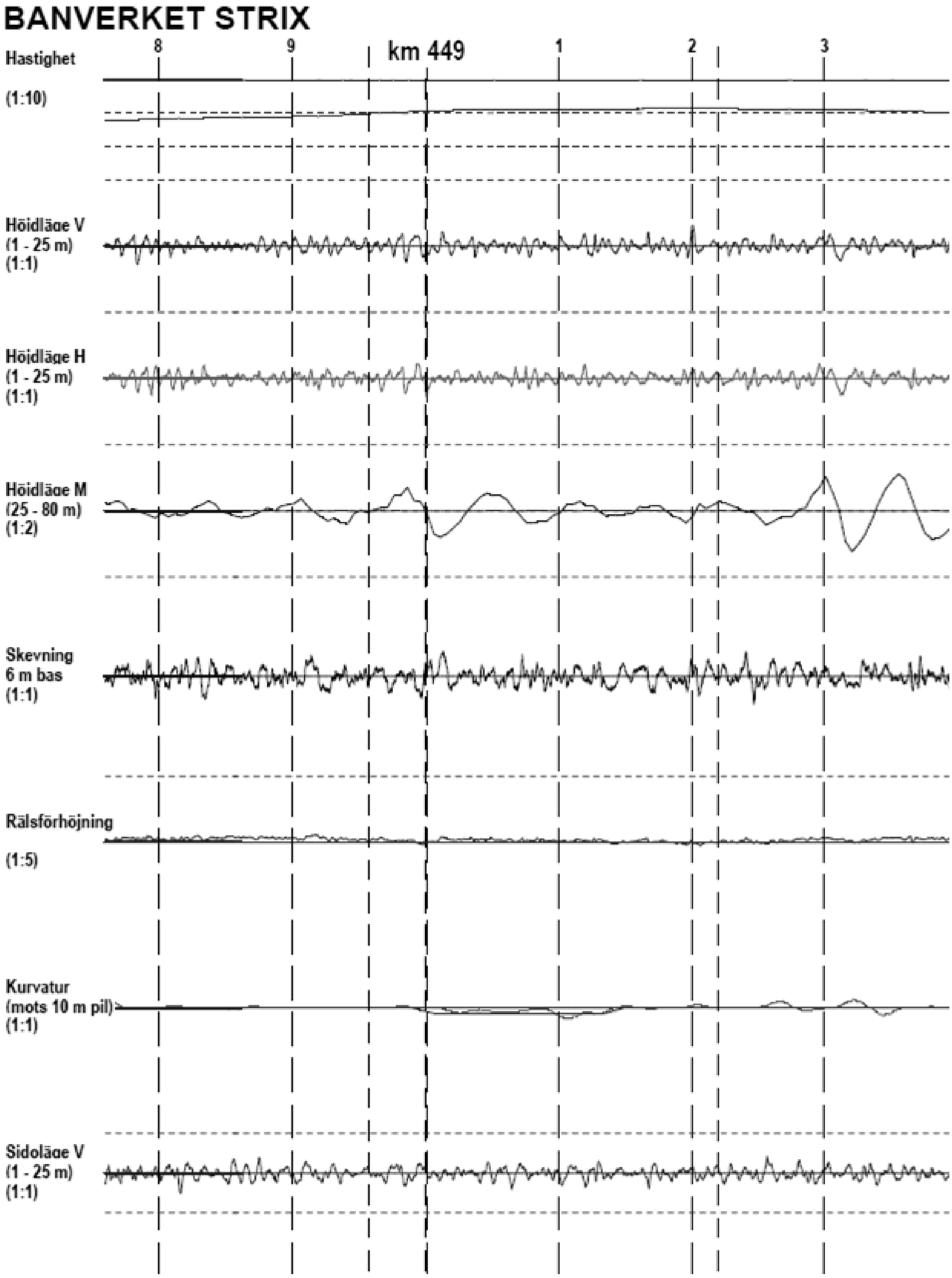
Banarbetstid i spår

- Hur fungerar det att få tider för spårriktning?
- Planeras banarbetstider i BAP eller BUP?

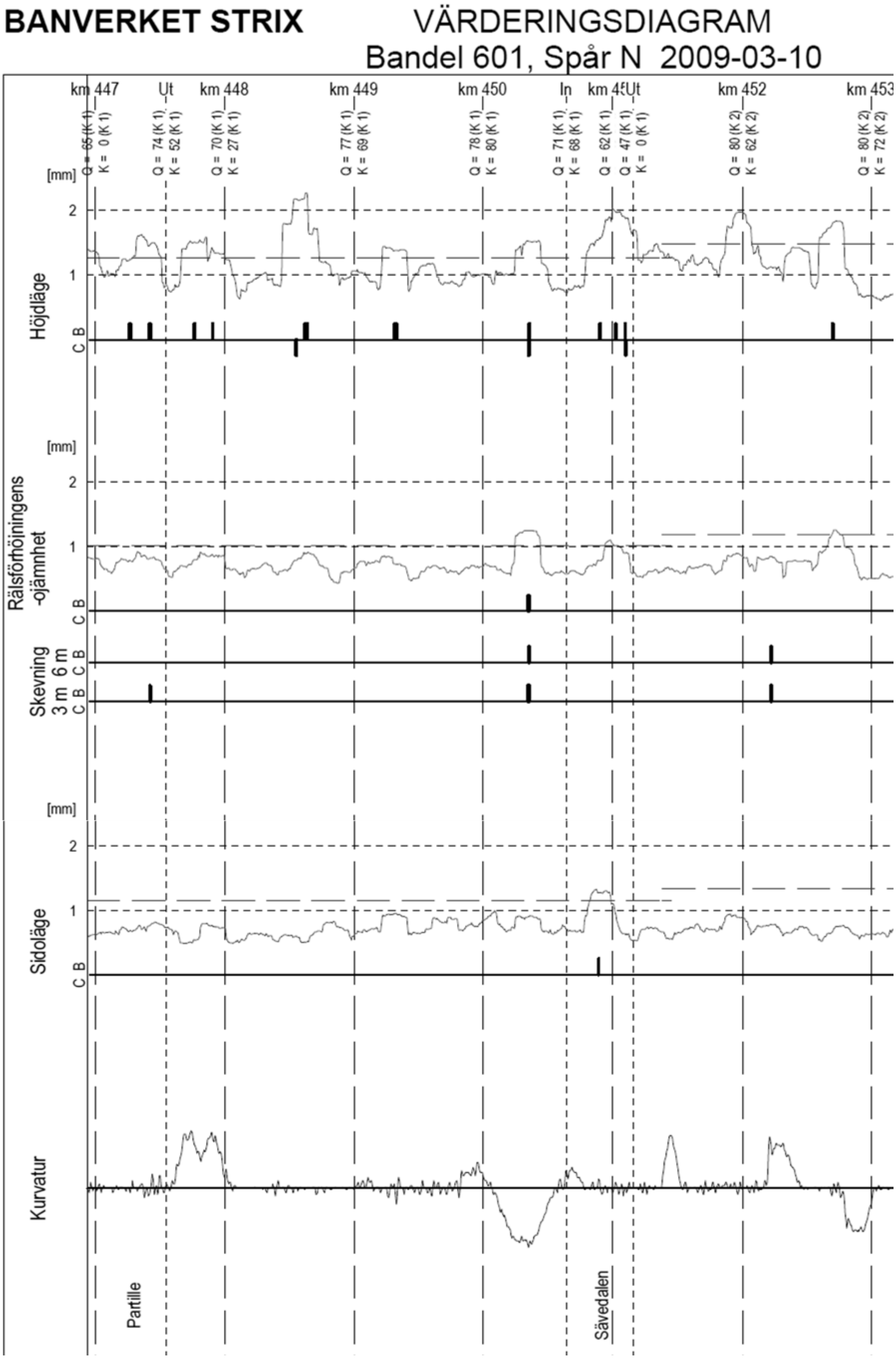
Uppföljning

- Hur besiktigas spårriktning/spårlägesstatus på banan?
- Hur upplever du att kvaliteten är på besiktningen?
- Händer det att spårriktningsåtgärder inte ger något resultat? Vad beror detta på?
- Kontrollmäts era sträckor med mätvagn efter utför spårriktning?
- Finns det någon rekommendation att detta/när detta ska utföras?
- Utförs någon analys/uppföljning av resultatet av planering av spårriktning (utöver besiktningen)?
- … av resultatet efter spårriktning?
- Vilka verktyg skulle du önska för att göra utföra en sådan uppföljning?

Appendix II –Example of TGQ diagram as PDF



Appendix III – Example of Valuation diagram



Appendix IV – Example of Quality list

BANVERKET STRIX KVALITETSLISTA **Sid 1**

Bandel 601, Spår N 2009-05-05

Sträcka: P - Sel Spår: N1

PUNKTFEL

Kolumn B: Antal meter där underhållsgräns men ej akutgräns överskrids
Kolumn C: Antal meter där akutgräns överskrids
Kolumn T: Antal meter där spårvidden är mindere än 1430
Fel>B-gräns: Antal meter resp. ställen där något av utslagen (ej spårvidden) överskrider uh-gräns

			Underhåll						Akut						Spv	Fel>B-gräns	
Från:	Till:	Längd (mätt)	Höjd	Rfh	Skevning 3 m	Skevning 6 m	Sido	Spv	Höjd	Rfh	Skevning 3 m	Skevning 6 m	Sido	Spv		(ej spårvidd)	
km+m	km+m	m	B	B	B	B	B	B	C	C	C	C	C	C	T	m	ställen
446+ 940	446+ 998	58	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0
447+ 0	447+ 551	552	6	-	1	-	-	7	-	-	-	-	-	-	-	7	2
447+ 551	447+ 998	447	-	-	-	-	-	75	-	-	-	-	-	-	-	0	0
448+ 0	448+1000	1001	1	-	-	-	1	1	-	-	-	-	-	-	-	2	2
449+ 0	449+ 997	998	-	-	-	-	-	-	-	-	-	-	-	-	2	0	0
450+ 0	450+ 641	642	4	2	3	-	1	15	-	-	-	-	-	-	2	6	2

SPÅRLÄGESVÄRDERING

Medelvärde för standardavvikelsen, sigma, för respektive värderingslinje samt kvalitetstal Q och K

Från: km+m	Till: km+m	Längd m	Kval. klass	Höjdläge sigmaH	Rfh ojämnhet sigmaR	Sidoläge sigmaP	Samverkan sigmaS	Q-tal	K-tal %
446+ 940	446+ 998	58	1	0.00	0.83	0.01	0.83	116	100
447+ 0	447+ 551	552	1	1.10	0.77	0.62	0.99	81	58
447+ 551	447+ 998	447	1	0.83	0.68	0.67	0.95	89	100
448+ 0	448+1000	1001	1	0.86	0.64	0.67	1.01	86	88
449+ 0	449+ 997	998	1	0.62	0.59	0.72	0.87	98	100
450+ 0	450+ 641	642	1	0.90	0.75	0.85	1.22	77	100

SAMMANSTÄLLNING

Stationsområde och linjespår

					Värderingslinje		Punktfel		Kvalite	
Sträcka:	Från:	Till:	Längd (mätt)	Kval. klass	Höjd-läge	Sam-verkan	Fel>B-gräns (ej spårvidd)		Q-tal	K-tal
	km+m	km+m	m		sigmaH	sigmaS	m	ställen		%
P	446+ 940	447+ 551	610	1	0.99	0.97	7	2	84	61
P - Sel	447+ 551	450+ 641	3088	1	0.79	1.00	8	4	88	96