Pavement Performance Models 2

Network Level Analysis

Validation of Performance Models

grafisk.senter@vegvesen.no 0077-10 foto: colourbox.com

<table>
<tr><td>NordFoU

Nordic Cooperation Program</td><td>Report title:

Validation of Performance Models</td></tr>
<tr><td rowspan="2">Project:

Pavement Performance Models 2 (NordFoU - PPM2)</td><td>Report no.: 1</td></tr>
<tr><td>Written by:

Asmus Skar, Mogens Løvendorf Holst, Jakob Larsen, Susanne Baltzer & Mikkel Mollerup</td></tr>
<tr><td>Participating countries:

Denmark, Iceland, Norway, Sweden</td><td rowspan="2">Checked by:

Mogens Løvendorf Holst & Susanne Baltzer</td></tr>
<tr><td>Leading country: Denmark</td></tr>
<tr><td>Project Leader: Susanne Baltzer</td><td>Date: May 2014</td></tr>
<tr><td colspan="2">Summary:

In the NordFoU - Pavement Performance Models (PPM) project in 2010 a set of pavement performance models for flexible pavement structures as well as a software application for prediction of pavement performance on network level were presented.

In the current phase of the project (Pavement Performance Models 2 (PPM2) - Validation of Performance Models) the pavement performance models have been calibrated for Nordic conditions based on historical data from test sections in the Nordic countries. Thus in PPM2 calibration factors have been determined and for Sweden and Norway future roughness and rutting can be predicted and for Denmark roughness. It has not been possible to determine calibration factors for Iceland due to the limited available data.

The pavement performance models as well as the recommended calibration factors have been implemented in the '3xP Nordic' software.</td></tr>
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Preface

NordFoU is a cooperation program for Nordic countries aimed at research and development in the road sector. The program was formally established in 2004 by the road authorities of the Nordic countries.

The NordFoU - Pavement Performance Models (NordFoU - PPM) project was one of the research and development projects initiated under the cooperation program. The objectives of the project were to evaluate, improve and adopt existing pavement performance models to Nordic conditions. Norway, Denmark, Sweden, and Iceland participated in the project with Norway having the responsibility for the overall management of the project. The project was divided into two main parts:

- Part 1 - network level models - lead by the Danish Road Directorate
- Part 2 - project level models - lead by the Swedish Road Administration

In the beginning of 2012 a second phase of the PPM project was initiated for the network level models under the title Pavement Performance Models 2 (PPM2) - Validation of Performance Models. This report presents the findings of the PPM2 project.

The project was guided by a steering committee comprised of representatives from the participating countries. Members of the steering committee were:

- Leif Bakløkk - Norway (chairman of the steering committee)
- Rabbira Garba Saba - Norway (Project leader)
- Anders Huvstig - Sweden
- Tomas Winnerholt - Sweden
- Gregers Hildebrand - Denmark
- Haraldur Sigurdsteinsson - Iceland

CONTENTS

APPENDICES

1 Introduction

The NordFoU cooperation program was established in 2004 to coordinate the research and development activities of the road authorities in the Nordic countries. Under this cooperation program the NordFoU Pavement Performance Model (PPM) project was one of the research projects initiated.

By the end of 2010, a set of pavement performance models for flexible pavement structures as well as a successful MATLAB software application for prediction of pavement performance on network level were presented together with the finalization of the PPM project reports. The suitability of the pavement performance models and the MATLAB software application resulted in further interest for the PPM work, and thus a second phase of the PPM project was initiated in the beginning of 2012 under the title Pavement Performance Models 2 (PPM2) - Validation of Performance Models.

The present PPM2 project is executed by the road administrations in Denmark (lead), Sweden, Norway and Iceland. In the PPM2 project the MATLAB software application has been named 'Pavement Performance Prediction Nordic', and is hereafter referred to as '3xP Nordic'.

When the '3xP Nordic' software was developed under the PPM project a limited number of test sections, all located in the southern part of Sweden, was used for calibration. The PPM2 project will mainly deal with calibrating the '3xP Nordic' software for an increased number of test sections from Sweden, Norway, Denmark and Iceland to include a wider spectrum of climate zones and materials. Furthermore the PPM2 project aim at improving the stability of the software and develop a user friendly software interface as well as user guidelines, see Ref. /1/.

The goal of the PPM2 is to deliver a software for prediction of future conditions of flexible pavement strucutures on network level as accurately as possible, calibrated for Nordic climate conditions.

The findings from the previous PPM project on network level can be seen in the following reports:

- PPM, Network Level Models - Identification and Selection of Pavement Performance Models, Ref. /1/
- PPM, Network Level Models - Development of Performance Measures, Modelling and calibration, Ref. /3/
- PPM, Network Level Models - Implementation and dissemination, Ref. /4/

The reports listed above are available at www.nordfou.org/.

2 Background

The present PPM2 is a continuation of the PPM project finalized by the end of 2010; this work was divided into the following two parts:

- Part 1 - PPMs at network level (Danish component)
- Part 2 - PPMs at project level (Swedish component)

At network level it was chosen to use the deterioration models from the HDM-4 program, which predicts the future performance of the road over time. As input for the deterioration models the traffic load, pavement structure, present condition of the road, climate et cetera are described through a number of input parameters and the deterioration of a given road is reported in relation to change in a number of parameters such as bearing capacity, roughness, cracking, rutting et cetera.

As the road deteriorates over time these parameters are changed, however the rate of change can be adjusted with a set of calibration factors in order to calibrate the deterioration models to local conditions. In the PPM project in 2010 a comprehensive study of the effect of both input parameters and calibration factors was carried out and the deterioration models from HDM-4 calibrated to Nordic conditions through adjustment of the relevant calibration factors based on historical data from Swedish Long Term Pavement Performance (LTPP) databases.

Furthermore the HDM-4 deterioration models were implemented in MATLAB and a software application was created for simulation and calibration purpose. Not all calibration factors could be optimized in the PPM project in 2010 due to lack of detail in the historical data and thus the deterioration models were only calibrated against time to initiation of cracking as well as development of rutting and roughness. Furthermore only a minor part of the available historical, Swedish data was used for the calibration process in 2010 due to time limitations.

In PPM2 the user interface of the MATLAB software application is to be improved and the calibration of the deterioration models for Nordic countries to be based on a larger number of test sections. All test sections should be with flexible pavement structures, but for a wider variety of Nordic countries; both in order to increase the accuracy of the prediction models, but also to cover a larger spectrum of climate zones and materials.

Finally the larger number of test sections might result in more sets of calibration factors depending on input parameters such as e.g. traffic volume, subgrade stiffness, Structural Number etc.

3 Test sections

3.1 Data collection

In the PPM2 project one of the first tasks was to specify requirements for the test sections and historical data that was needed to create robust pavement performance models representative of the Nordic conditions, both with regard to climate and pavement structures. These optimum wishes for test sections were communicated to the Nordic countries as well as a spreadsheet (data sheet) with instructions on which specific historical data was desired for each test section.

The requirements for test sections and historical data are listed below:

› It shall be flexible pavement structures.

› For each road section information is required on climate, pavement structure and traffic data as well as historical condition measurements for bearing capacity, roughness, rutting and crack recording (if any).

› Test sections shall have condition measurements describing at least a five year period. There shall be recordings in at least three years (three data points). No overlays shall have been placed within this period.

› As many climatic zones as possible are requested; preferably three or more roads in each climate zone.

› It will be extremely valuable if possible to embrace the span of different flexible pavement structures in each country, by for example providing pavement structures with thin/thick asphalt layers.

› It will be valuable with road sections trafficked by vehicles with studded tires. Again, preferably three or more test roads with studded tires.

The result of the data collection from each country is presented in the following chapters.

Preliminary it should be noted that Sweden has a very unique program for systematic data collection on a large number of test sections; hence Sweden has provided data of a very high quality. Denmark, Norway and Iceland do not have systematic programs of data collection on test sections, and therefore had to use test sections measured during routine network monitoring, which do not necessarily provide all the required data.

3.2 Test sections in Sweden

In the PPM project in 2010 the calibration of the '3xP Nordic' software was based on five test sections in Sweden; these five test sections as well as seven additional test sections are used the calibration in PPM2, see list of all 12 test sections below:

- National Highway 60 (RV60) close to Borlänge
- National Highway 71 (RV71) close to Äppelbo
- National Highway 80 (RV80) close to Bjursås
- National Highway 90 (RV90) close to Sollefteå
- Local Road 675 (Road 675) close to Kaxås
- National Highway 31 (RV31) close to Nässjö
- National Highway 34 (RV34) close to Målilla
- National Highway 46 (RV46) close to Trädet
- European Highway E6-1 (E6 (F)) close to Fastarp
- European Highway E6-1 (E6 (T)) close to Tvååker
- National Highway 35 (RV35) close to Kvicksund
- National Highway 45 (RV45) close to Häggenås

The test sections above are plotted on a map in the figure below:

Figure 3-1. Location of test sections in Sweden.

The climatic conditions, pavement structure, traffic and subgrade strength for each test sections in Sweden can be seen in Appendix A.

The test sections are flexible asphalt roads with a traffic load expressed in Equivalent Standard Axle loads (ESALs) ranging from app. 8,000 (Road 645) to 745,000 (E6). Roughness and rutting measurements have been carried out for all the Swedish test sections in a period of 5 to 13 years and the results are compiled in the LTPP database, see Ref. /5/. In this database each test section is divided into 5 to 12 uniform subsections (all input parameters are equal) and measurements were performed on and reported for each subsection.

In the two figures below the average measured values for these subsections are illustrated for each test section in regards of roughness expressed as IRI[1] and rutting, respectively:

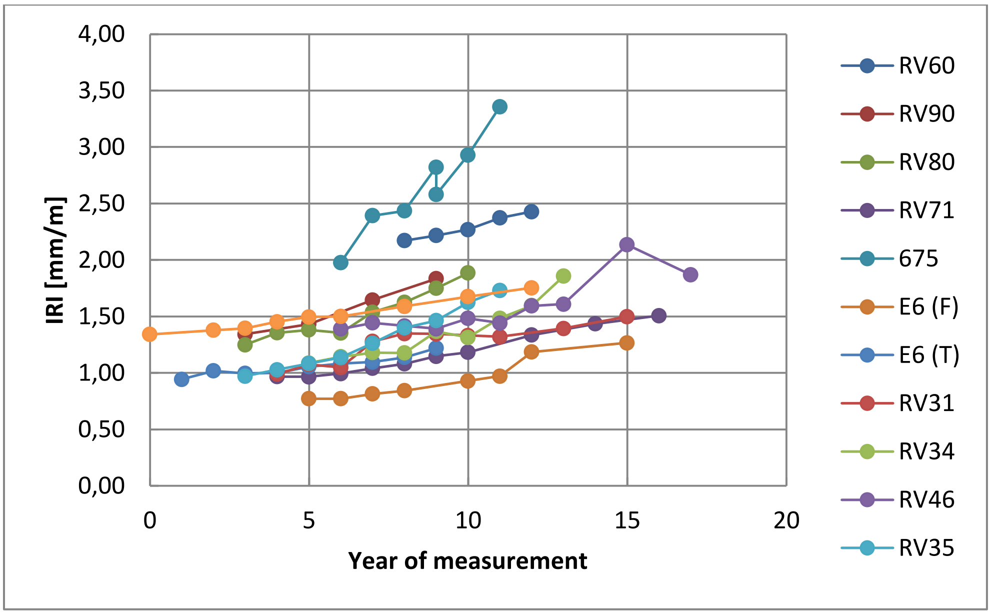

Figure 3-2. Development of average measured IRI for the test sections in Sweden (year 0 corresponds to year of construction).

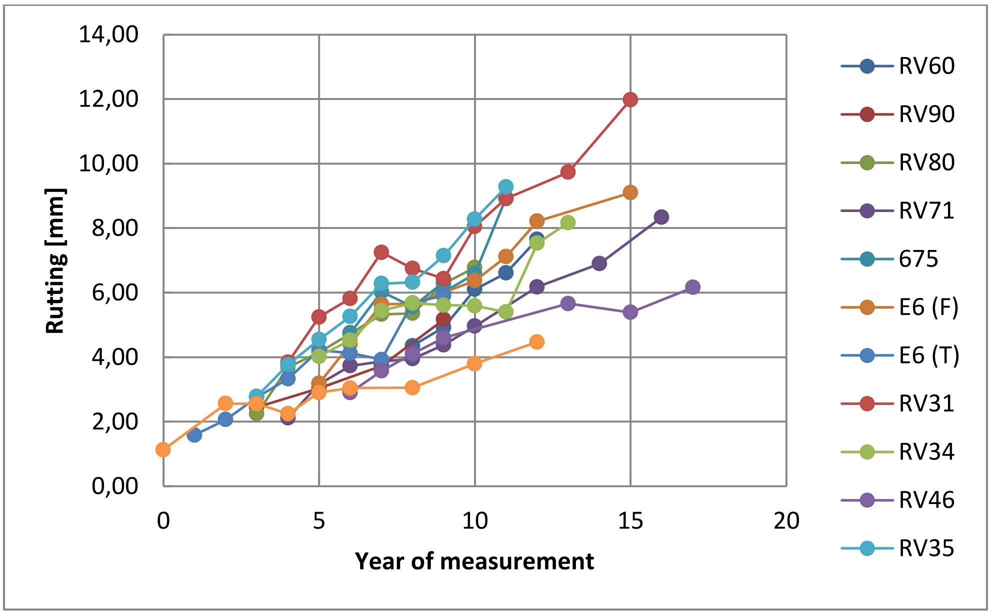

Figure 3-3. Development of average measured rutting for the test sections in Sweden (year 0 corresponds to year of construction).

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[1] IRI: International Roughness Index.

3.3 Test sections in Norway

In total data for four test sections in Norway was obtained for the calibration of the '3xP Nordic' software in PPM2, see list of test sections below:

- National Highway 5 (RV5) close to Førde in Sogn and Fjordane County
- European Highway 39 (E39) close to Nordfjordeid in Sogn and Fjordane County
- European Highway 6 (E6) close to Trondheim on the border between Sør- and Nord Trøndelag County
- European Highway 8 (E8) close to Tromsø in Troms County

The test sections above are plotted on a map in the figure below:

Figure 3-4. Location of test sections in Norway.

The climatic conditions, pavement structure, traffic and subgrade strength for each test sections in Norway can be seen in Appendix A.

The test sections are flexible asphalt roads with a traffic load expressed in ESALs ranging from app. 33,000 (RV5 and E39) to 327,000 (E6). Roughness and rutting measurements have been carried out for all the Norwegian test sections in a period of 8 to 11 years.

In the two figures below the measured values are illustrated for each test section in regards of roughness expressed as IRI and rutting, respectively:

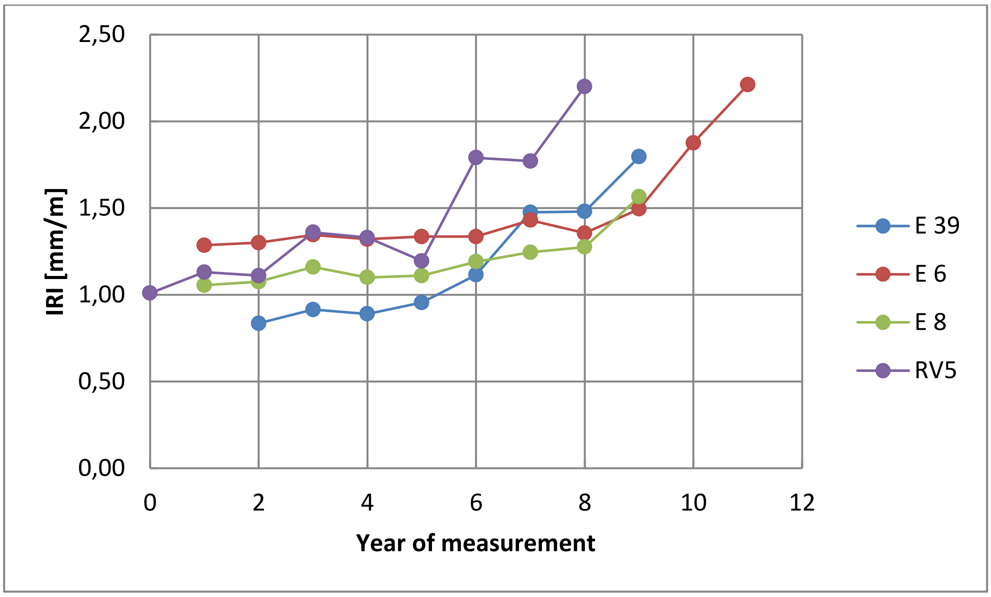

Figure 3-5. *Development of average measured IRI for the test sections in Norway (year 0 corresponds to year of construction).*

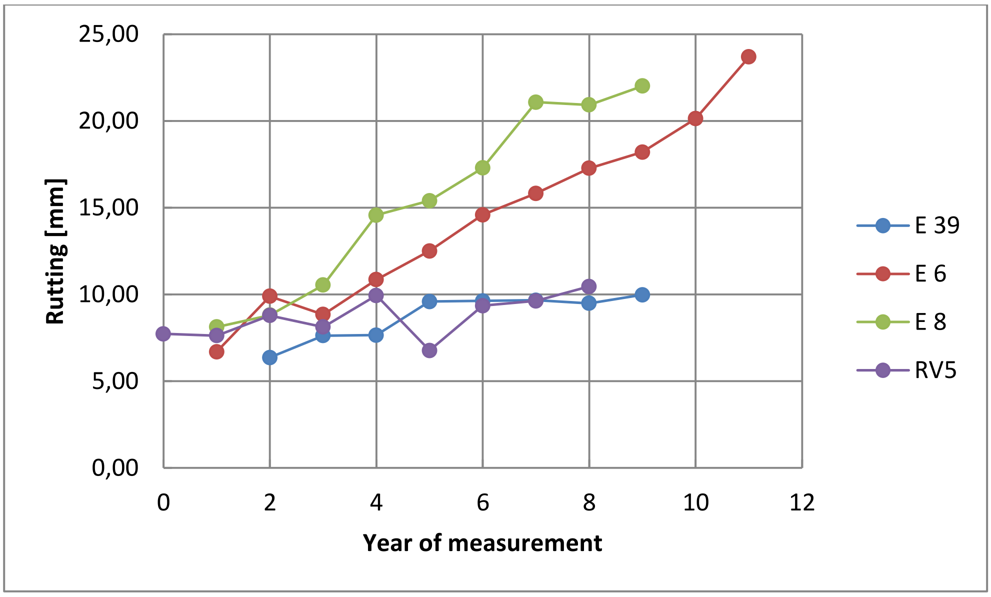

Figure 3-6. *Development of average measured rutting for the test sections in Norway (year 0 corresponds to year of construction).*

3.4 Test sections in Denmark

In total data for three test sections in Denmark was obtained for the calibration of the '3xP Nordic' software in PPM2. Two of these test sections have been divided into two non-uniform subsections and thus they constitutes a test section on their own, see list of test sections below:

- National Highway M90 close to Aalborg
  - M90-1: Chainage 9.0 - 14.6
  - M90-2: Chainage 52.0 - 57.6
- National Highway M64 close to Herning
  - M64-1: Chainage 42.500 - 55.610
  - M64-2: Chainage 55.610-55.876
- Local road 344 close to Brande

The test sections above are plotted on a map in the figure below:

Figure 3-7. Location of test sections in Denmark.

The climatic conditions, pavement structure, traffic and subgrade strength for each test sections in Denmark can be seen in Appendix A.

The test sections are flexible asphalt roads with a traffic load expressed in ESALs ranging from app. 342,000 (Road 344) to 1,200,000 (M90). Roughness and rutting measurements have been carried out for all the Danish test sections in a period of 5 to 8 years.

In the two figures below the measured values are illustrated for each test section in regards of roughness expressed as IRI and rutting, respectively:

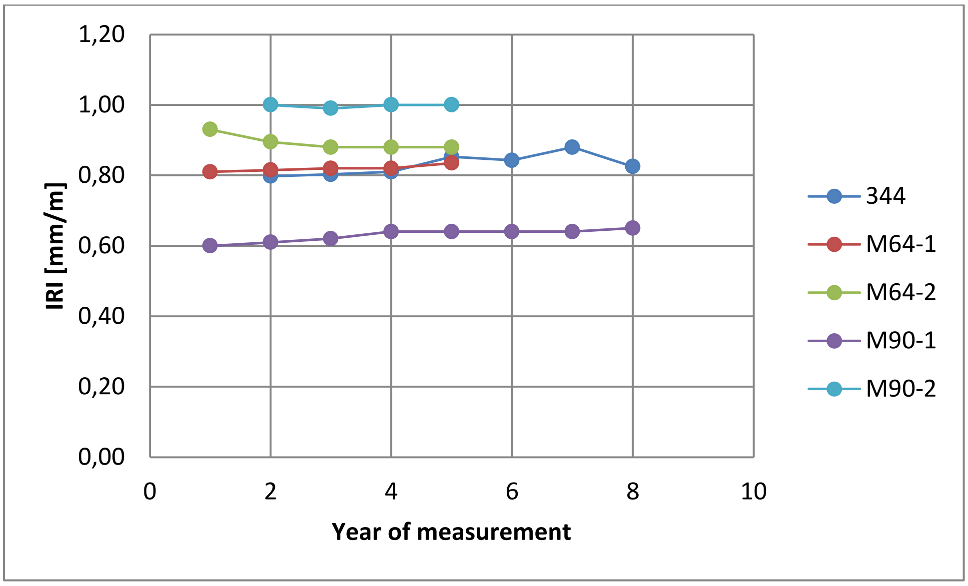

Figure 3-8. *Development of average measured IRI for the test sections in Denmark (year 0 corresponds to year of construction).*

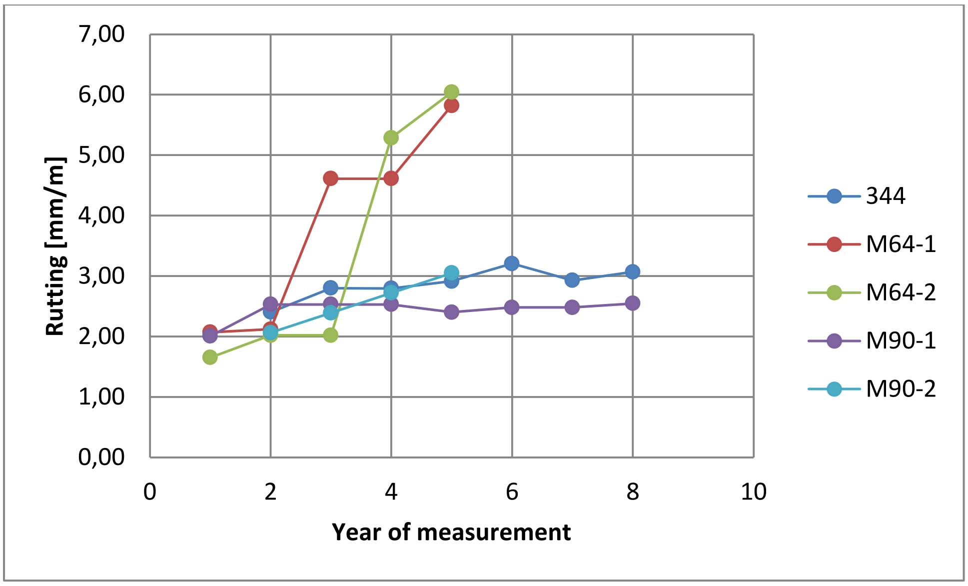

Figure 3-9. *Development of average measured rutting for the test sections in Denmark (year 0 corresponds to year of construction).*

3.5 Test sections in Iceland

For Iceland data for 15 test sections were submitted, however for all but two test sections only data for one year of measurement were included. The following two test sections have been investigated in the PPM2, but for both only data for roughness is provided for two different years:

- Road 1, chainage G8 close to Bjóõvegur
- Road 38, chainage 01 close to Hveragerõi

Due to the limited amount of data the test sections from Iceland cannot be used for the calibration of the '3xP Nordic' software in PPM2; however the calibration factors found from the other test sections will be used on the above two test sections from Iceland and the correlation between predicted and measured performance / distress evaluated.

The test sections above are plotted on a map in the figure below:

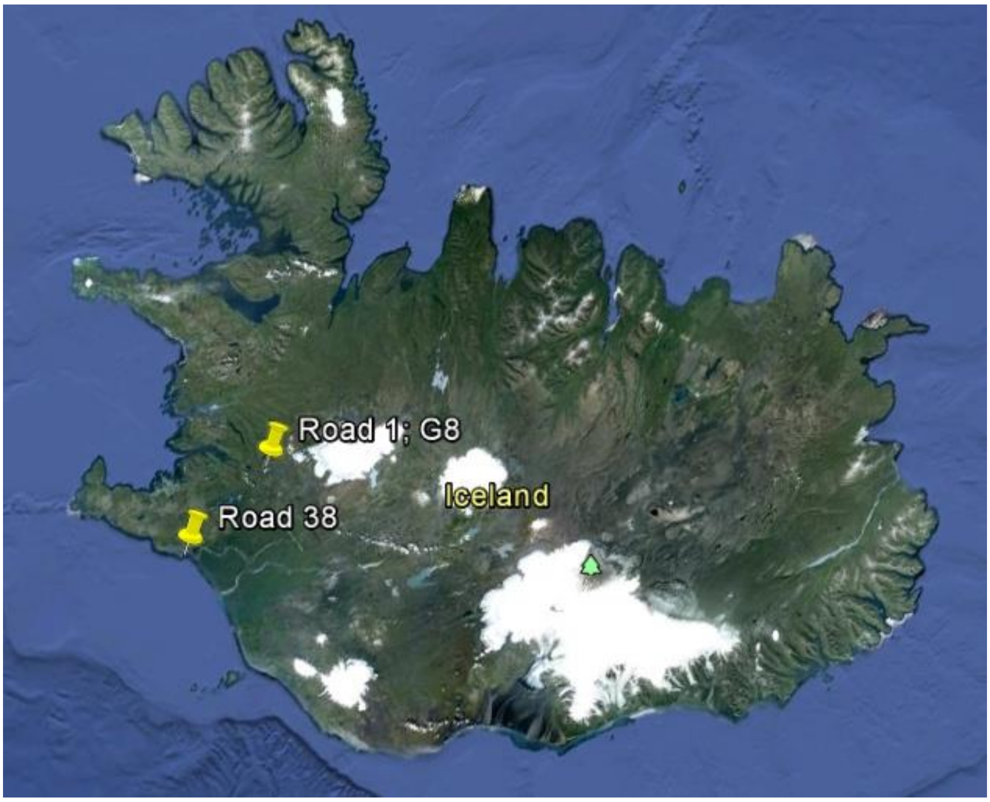

Figure 3-10. Location of test sections in Iceland.

The climatic conditions, pavement structure, traffic and subgrade strength for each test sections in Iceland can be seen in Appendix A.

Road 38 is a flexible asphalt road, but Road 1 has a bound base (foamed asphalt with an elastic modulus of 600 MPa). Thus Road 1 can not necessarily be classified as a flexible pavement structure, but due to the limited number of test sections for Iceland the pavement performance models with the calibration factors determined in PPM2 for the other test sections will still be used for evaluation of this road.

The two test sections have a traffic load expressed in ESALs ranging from app. 81,000 (Road 38) to 407,000 (Road 1). Roughness measurements have been carried out for these two Icelandic test sections 6 years apart, whereas there is only one measurement in regards of rutting.

In the two figures below the measured values are illustrated for each test section in regards of roughness expressed as IRI and rutting, respectively:

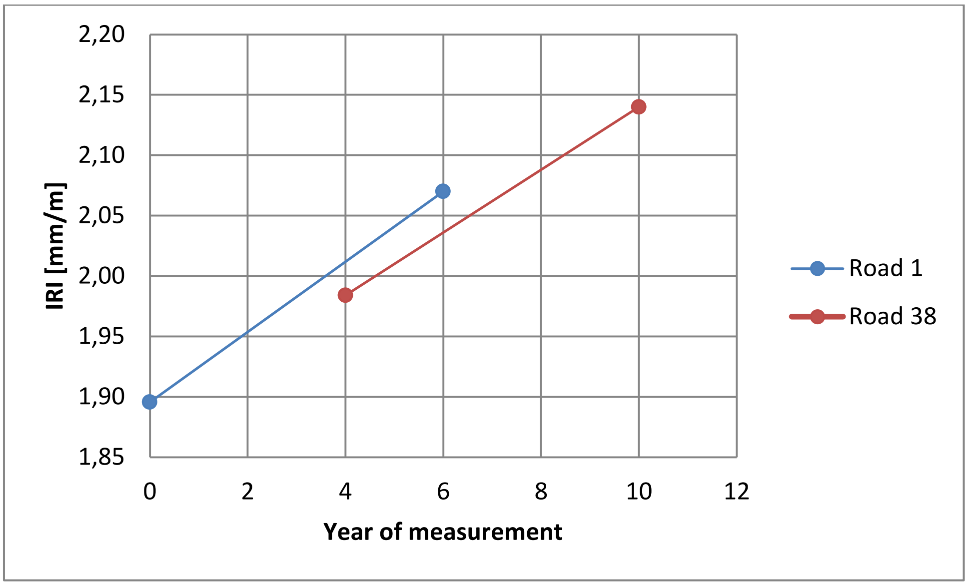

Figure 3-11. Development of average measured IRI for the test sections in Iceland (year 0 corresponds to year of construction).

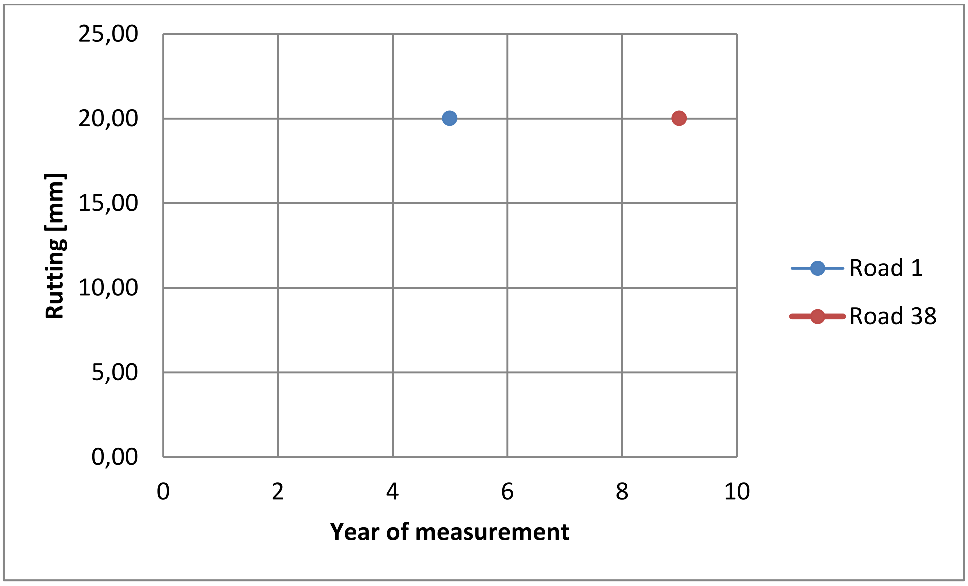

Figure 3-12. Measured rutting for the test sections in Iceland (year 0 corresponds to year of construction).

4 Calibration of '3xP Nordic'

4.1 Deterioration / distress parameters used in calibration

In the PPM 2 project the following deterioration / distress parameters are used to calibrate the pavement performance models from HDM-4:

› Cracking
› Roughness
› Rutting

The calibration process is described in the chapters below.

4.2 Test sections used for calibration

In Chapter 3 the test sections for Sweden, Norway, Denmark and Iceland are listed. In the Swedish LTPP database, see Ref. /5/, each test section is divided into uniform subsections where all input parameters such as e.g. pavement structure and traffic loading are equal. However, deterioration of these uniform subsections will inevitably vary due to a number of factors such as variation in construction due to construction tolerances, natural variation in materials and subgrade et cetera. As these variations are unintentional and mostly unaccounted for, the average value of the calibration factors for these subsections will be reported for the test section.

4.3 Input parameters for test sections used for calibration

During the PPM project in 2010 it was found that some input parameters did not have any effect on the deterioration models. Thus as described in Chapter 3.2.4 in Ref. /3/ some input parameters were assumed to be standard for all test sections, see Appendix 3 in Ref. /3/, while other input parameters are section specific and thus appropriate values should be determined for each individual test section or subsection. This approach has also been adopted in PPM2 and standard input parameters are listed in Appendix B.

Based on the historical data available the section specific input parameters for each test section used for calibration in the PPM2 project are detailed in Appendix C.

4.4 Calibration of '3xP Nordic' based on historical data

4.4.1 Calibration methodology

The methodology used in the calibration process in the PPM project in 2010 was outlined in Chapter 3.2.6 in Ref. /3/. This methodology can be summarized as the following steps:

- Step 1: Determine calibration factors directly from the historical data
- Step 2: Calibrate predicted development of cracking to historical data
- Step 3: Calibrate the predicted development of rutting to historical data
- Step 4: Calibrate the predicted development of roughness to historical data

During the PPM project in 2010 it was found that some calibration factors did not have any effect on the deterioration models, while other calibration factors adjusted the development of a distress type for which data could not be determined from the historical data. These calibration factors were excluded from the calibration process in the PPM project in 2010, were assigned default values from the HDM-4 program and were referred to as standard calibration factors, see list in Appendix 4 in Ref. /3/.

Based on the findings in the PPM project from 2010 it was concluded that the development of cracking (Step 2) can not be calibrated from the historical data available as these do not distinguish between type of crack. Thus default values in the HDM-4 program were used for these section specific calibration factors in 2010.

As a consequence the methodology used in the calibration process in PPM2 was modified to include the following steps:

- Step 1: Determine calibration factors directly from the historical data
- Step 3: Calibrate the predicted development of rutting to historical data
- Step 4: Calibrate the predicted development of roughness to historical data

Thus in PPM2 the calibration factors related to cracking that cannot be determined directly from the historical data are also considered having default values from the HDM-4 program, see complete list in Appendix D.

In the following Chapter 4.4.2 and 4.4.3 these remaining section specific calibration factors are found based on historical data in the present PPM2 project.

4.4.2 Calculated section specific calibration factors (Step 1)

The section specific calibration factors listed in the table below can (in theory) be calculated directly from the historical data:

Table 4-1. Section specific calibration factors that can be calculated directly from historical data used in the calibration process.

Section specific calibration factor	Description
K_{cia}	Calibration factor for the structural cracking initiation model.
K_{rid}	Calibration factor for the rutting initial densification model.

Calibration of K_{cia}

In HDM-4 the section specific calibration factor K_{cia} is part of an equation that calculates the time for initiation of cracking (ICA) in years; thus from the historical data the ICA can be determined as the year, when the first crack appears and based on this K_{cia} can be back-calculated.

As cracking has not been reported for the test sections in Norway and Denmark it is only from the historical data for the test sections in Sweden that ICA can be determined. For test sections in Sweden were no cracks have been registered the factor K_{cia} cannot be calibrated; thus a weighted average for all other Swedish test sections has been used in the present analysis.

In the calibration process it was found that using the calculated K_{cia} values in the '3xP Nordic' software does not result in the correct year for initiation of cracking compared to the historical data. Thus K_{cia} has been calibrated to match the time to initiation of cracking from the historical data; an overview of the calculated and calibrated value of K_{cia} for each test section are included under the heading E.1 in Appendix E.

Calibration of K_{rid}

The section specific calibration factor K_{rid} adjusts the initial densification (RDO) in mm.

After construction when a road is opened for traffic a number of factors can contribute to rutting; these are:

- Densification of asphalt layers
- Plastic deformation of asphalt layers
- Wear from studded tires

In the PPM project in 2010 the K_{rid} calibration factor was determined solely based on the initial densification, and thereby determined as being the difference between the measured rutting in year 0 and year 1. The problem with this approach is that most of the sections investigated in this project have no measurements in the first years after construction. As rutting measurements were performed 3-5 years after construction on most of the test sections, the initial densification cannot be calculated from the historical data; thus the K_{rid} factor was calibrated as a best fit approach. This approach has also been adopted in PPM2 and the result is included in Table 9-22 at the end of Appendix E.

4.4.3 Simulated section specific calibration factors (Step 3 - 4)

The section specific calibration factors listed in the table below can be determined through an iterative process to obtain the best fit of the output from the '3xP Nordic' software to the historical data:

Table 4-2. Section specific calibration factors that can be determined as best fit based on historical data used in the calibration process.

Section specific calibration factor	**Description**
K_{pp}	Calibration factor for the pothole progression model.
K_{rst}	Calibration factor for the rutting structural deterioration model.
K_{gm}	Calibration factor for the environmental roughness model.
K_{gs}	Calibration factor for the roughness model (structural contribution).
K_{gc}	Calibration factor for the roughness model (cracking contribution).
K_{gr}	Calibration factor for the roughness model (ravelling contribution).

The steps in the calibration process are detailed under the heading E.2 and E.3 in Appendix E and the results are included in Table 9-22 at the end of the same appendix.

4.5 Worked example of calibration process

The calibration process used in the present report has been detailed described in Appendix J as a worked example.

4.6 Results from calibration process

The results from the calibration process are included in Table 9-22 at the end of Appendix E. In this table the values for the section specific calibration factors are given for all sections including subsections based on historical data.

5 Evaluation of determined calibration factors

5.1 Introduction

In order to establish a set of values for Nordic calibration factors for roads on network level the results found in Chapter 4 should undergo further evaluation in relation to grouping and weighting of factors.

5.2 Evaluation of potential grouping

The calibration factors found in Chapter 4 vary from section to section, see e.g. Table 9-22 at the end of Appendix E; therefore both uniformity and grouping of data have to be evaluated in order to establish a reliable set of values for the calibrated calibration factors.

It is envisioned that the input parameters listed below could have great influence on the deterioration of the pavement structure and by grouping the test sections sets of calibration factors might be found:

- Heavy traffic: - Average Annual Daily Traffic for heavy traffic ($AADT_{heavy}$) or Equivalent Standard Axle Loads (ESALs)
- Bearing capacity: - Structural Number (SNP)
  - Subgrade strength
- Climate: - Mean Monthly Precipitation (MMP)

The analysis is included as Appendix F and show that there are no certain pattern that indicate classsification of the section specific calibration factors in relations to the above listed parameters.

Based on the analysis in Appendix F it has been decided to divide the calibration factors for Nordic countries into two sets of country specific calibration factors for each country and analyse the result from this:

- High heavy traffic
- Low heavy traffic

In Table 9-24 in Appendix F the calibration factors for each test section are given; in Appendix G these calibration factors are used to calculate seperate sets of calibration factors for Sweden, Norway and Denmark, both as overall average and for high and low heavy traffic, respectively.

In the table below the split between high and low heavy traffic for each country used in PPM2 is given:

Table 5-1. Split between high and low heavy traffic used in PPM2.

Country	$AADT_{heavy}$	
	High heavy traffic	Low heavy traffic
Sweden	≥ 1.000	< 1.000
Norway	≥ 150	< 150
Denmark	≥ 2.000	< 2.000

5.2.1 Sweden

Validation of prediction of rutting

In figure below the measured data for rutting can be seen against the predicted development of rutting using average calibration factors from all Swedish test sections (see Table 9-25). Furthermore the coefficient of determination (R^2) between the two is shown:

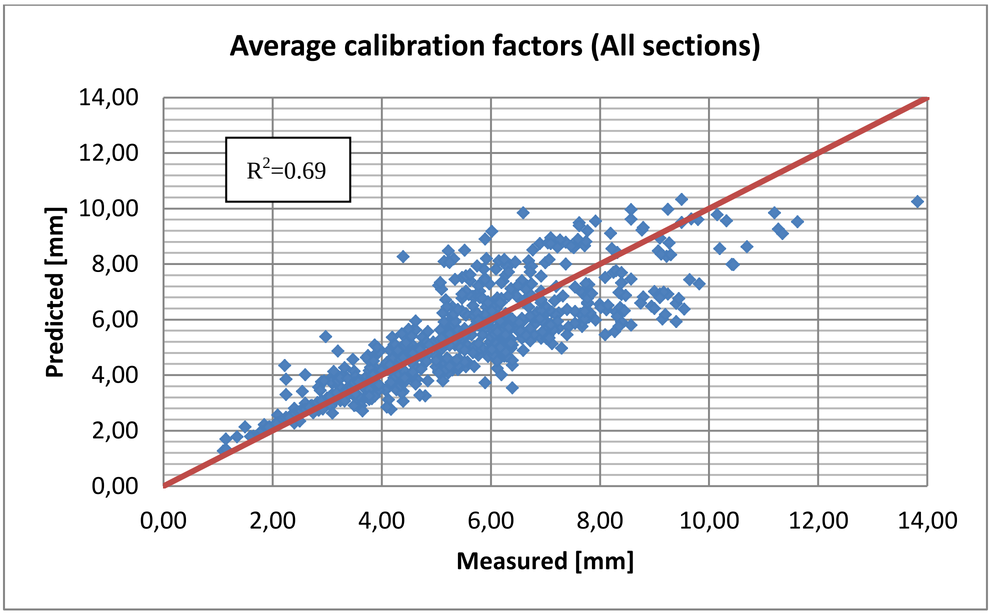

Figure 5-1. <u>All Swedish sections:</u> Correlation between measured and predicted rutting using the average calibration factors.

It can be seen from the figure above that there is a relatively good correlation between measured and predicted rutting for the Swedish test sections using average calibration factors for all Swedish sections; especially for the low values of rutting, which is within the first years of the pavement life. It is noted that the predicted rutting is increasingly spread out for the higher values of rutting, which will be within the later stages of the pavement life; this is partly caused by accumulation of errors in the prediction of rutting.

The two figures below show the measured rutting against the predicted rutting from the '3xP Nordic' software, when the Swedish test sections are divided in high and low heavy trafficked sections (see appropriate calibration factors in Table 9-25):

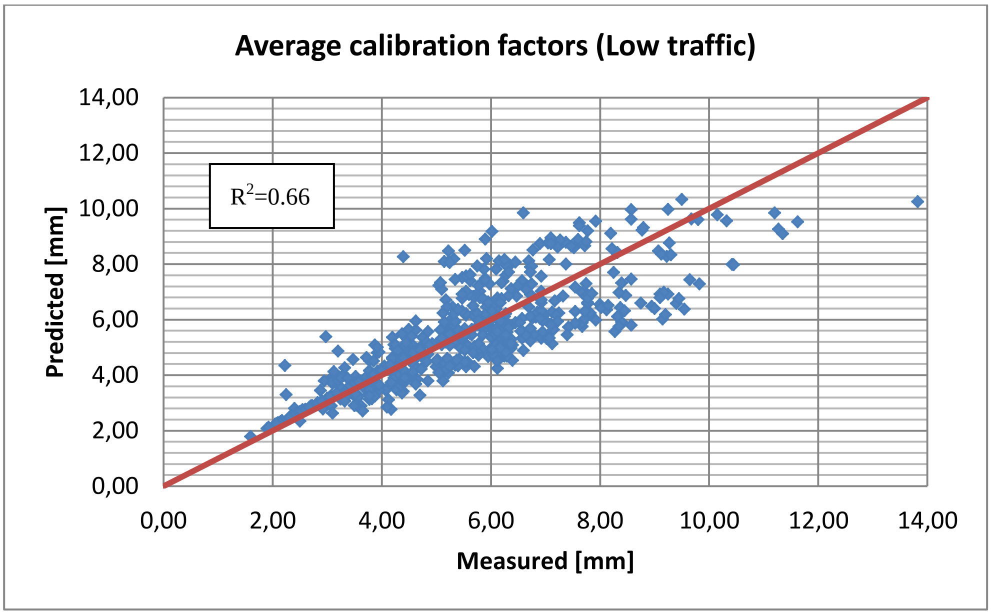

Figure 5-2. *<u>Low heavy trafficked, Swedish sections:</u> Correlation between measured and predicted rutting using the low heavy traffic calibration factors.*

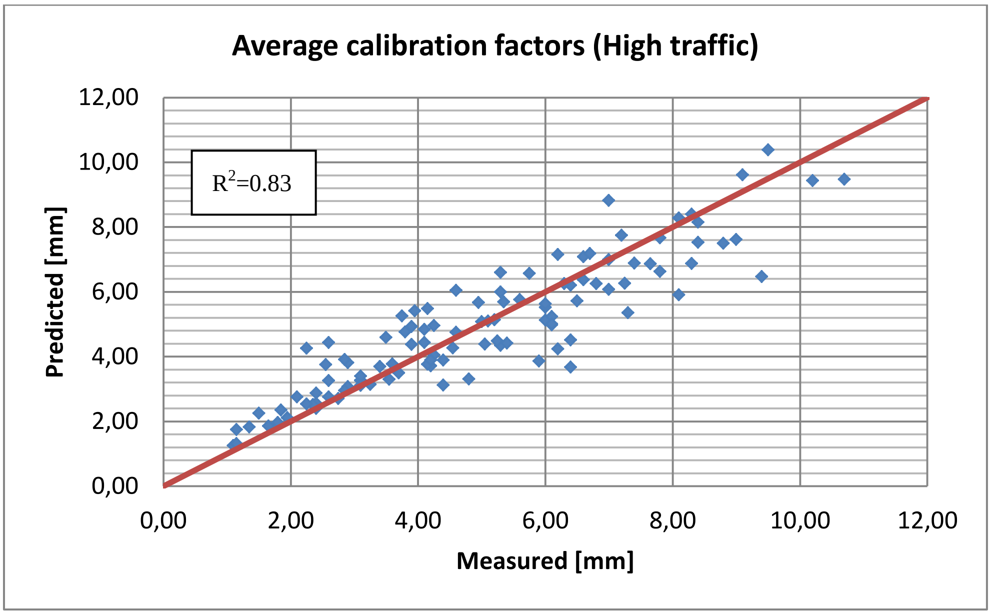

Figure 5-3. *<u>High heavy trafficked, Swedish sections:</u> Correlation between measured and predicted rutting using the high heavy traffic calibration factors.*

From the two figures above it can be concluded that splitting the calibration factors between high and low heavy trafficked sections, the coefficient of determination correlation for rutting is improved for the high heavy trafficked sections and slightly worse for the low heavy trafficked sections (from R^2 = 0.69 for all sections to R^2 = 0.83 and R^2 = 0.66 for high and low heavy traffic, respectively).

Validation of prediction of roughness

In figure below the measured data for roughness can be seen against the predicted development of roughness using average calibration factors from all Swedish test sections (see Table 9-25). Furthermore the coefficient of determination (R^2) between the two is shown:

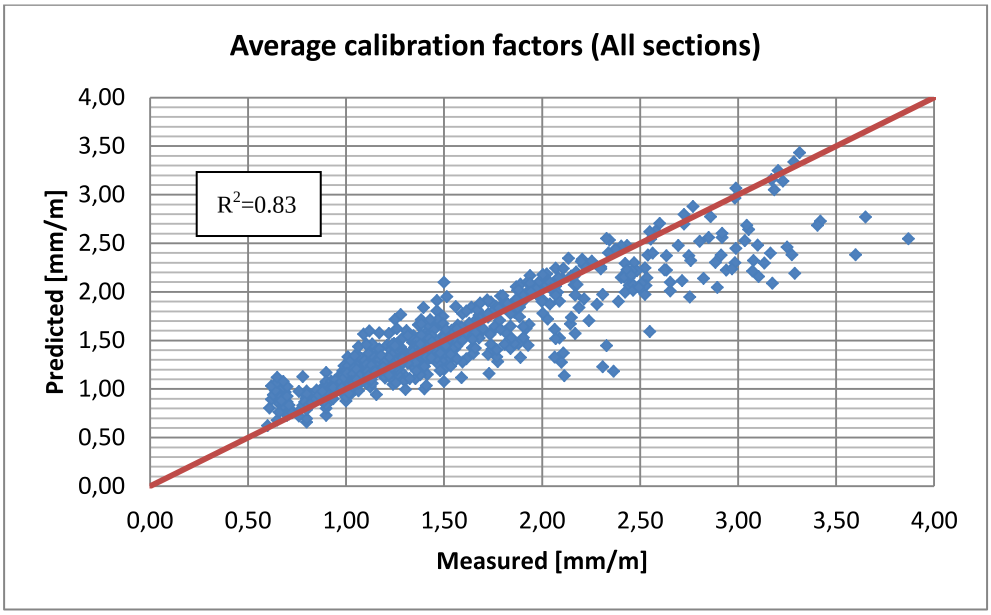

Figure 5-4. *<u>All Swedish sections:</u> Correlation between measured and predicted roughness using average calibration factors.*

It can be seen from the figure above that there is an acceptable to good correlation between measured and predicted roughness for the Swedish test sections using average calibration factors for all Swedish sections; as for the prediction of rutting the error increase as roughness develop over time. A somewhat better correlation is obtained for roughness than for rutting; this is a result of less difference between the section specific calibration factors on subsections.

The two figures below show the measured roughness against the predicted roughness from the '3xP Nordic' software, when the Swedish test sections are divided in high and low heavy trafficked sections (see appropriate calibration factors in Table 9-25):

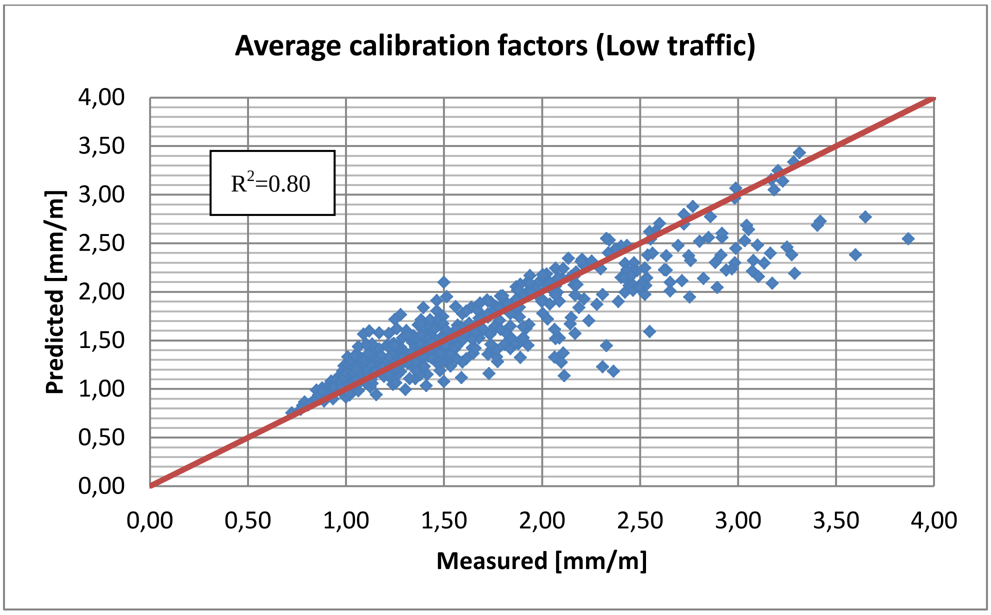

Figure 5-5. *<u>Low heavy trafficked, Swedish sections:</u> Correlation between measured and predicted roughness using the low heavy traffic calibration factors.*

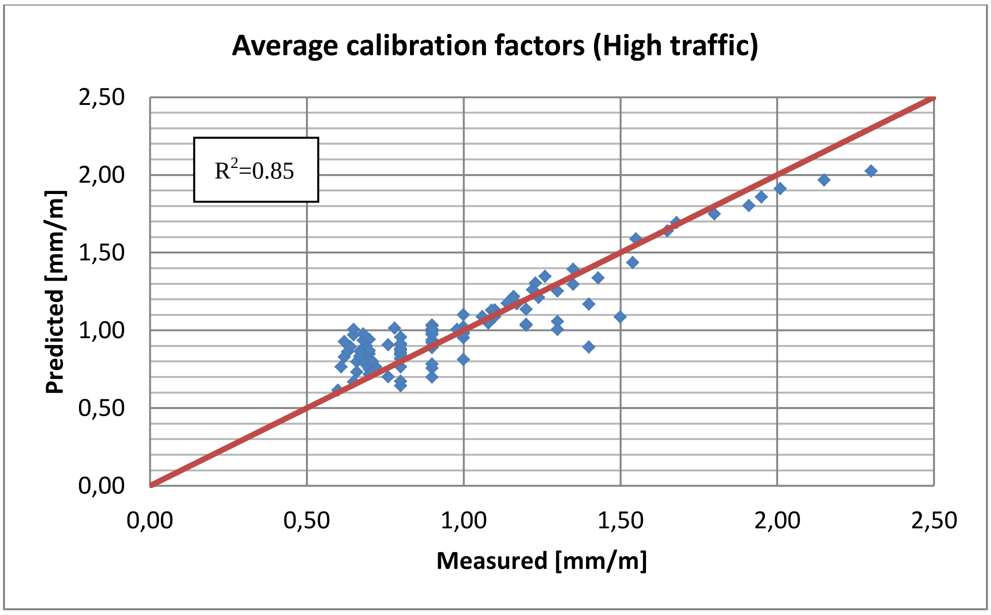

Figure 5-6. *<u>High heavy trafficked, Swedish sections:</u> Correlation between measured and predicted roughness using the high heavy traffic calibration factors.*

From the two figures above it can be concluded that splitting the calibration factors between high and low heavy trafficked sections, the coefficient of determination correlation for roughness is slightly improved for the high heavy trafficked sections and slightly reduced for the low heavy trafficked sections (from R^2 = 0.83 for all sections to R^2 = 0.85 and R^2 = 0.80 for high and low heavy traffic, respectively).

5.2.2 Norway

Validation of prediction of rutting

In figure below the measured data for rutting can be seen against the predicted development of rutting using average calibration factors from all Norwegian test sections (see Table 9-25). Furthermore the coefficient of determination (R^2) between the two is shown.

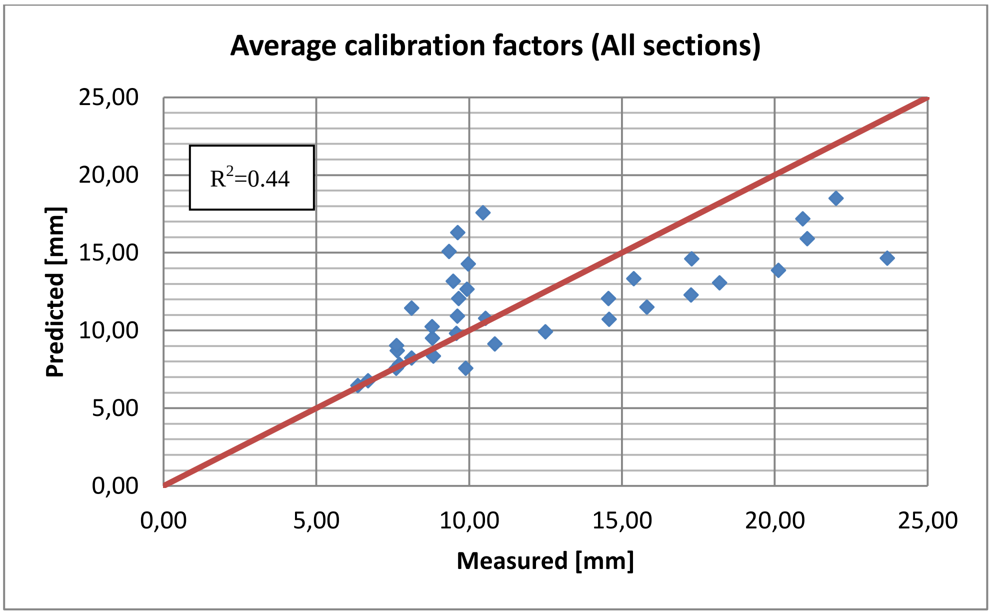

Figure 5-7. *<u>All Norwegian sections:</u> Correlation between measured and predicted rutting using the average calibration factors.*

It can be seen from the figure above that there is a relatively poor correlation between measured and predicted rutting for the Norwegian test sections using average calibration factors for all Norwegian sections.

The two figures below show the measured rutting against the predicted rutting from the '3xP Nordic' software, when the Norwegian test sections are divided in high and low heavy trafficked sections (see appropriate calibration factors in Table 9-25):

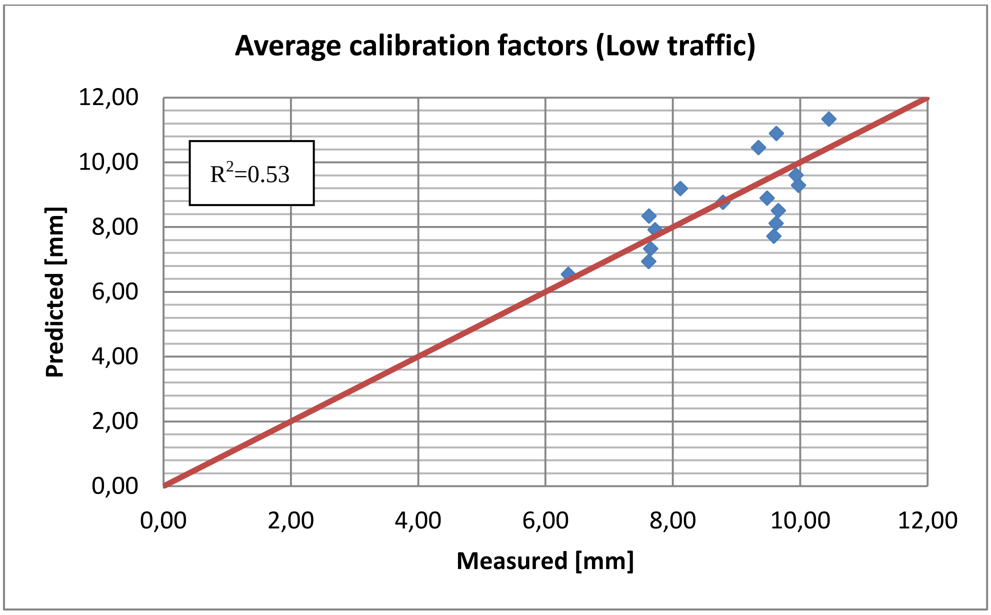

Figure 5-8. *<u>Low heavy trafficked, Norwegian sections:</u> Correlation between measured and predicted rutting using the low heavy traffic calibration factors.*

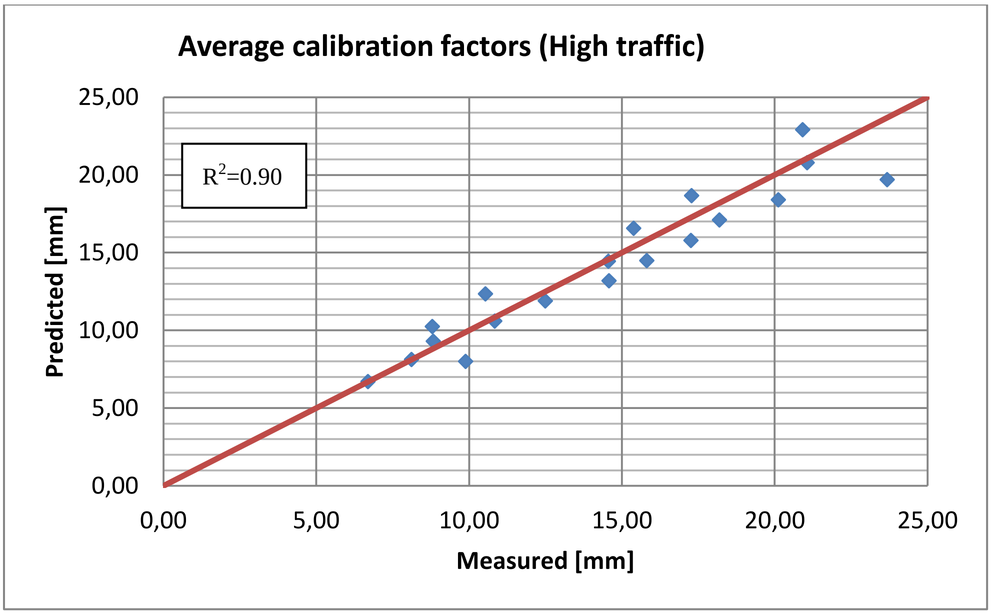

Figure 5-9. *<u>High heavy trafficked, Norwegian sections:</u> Correlation between measured and predicted rutting using the high heavy traffic calibration factors.*

From the two figures above it can be concluded that splitting the calibration factors between high and low heavy trafficked sections, the coefficient of determination correlation for rutting has improved significantly for the high heavy trafficked sections and some for the low heavy trafficked sections (from R^2 = 0.44 for all sections to R^2 = 0.90 and R^2 = 0.53 for high and low heavy traffic, respectively).

Validation of prediction of roughness

In figure below the measured data for roughness can be seen against the predicted development of roughness using average calibration factors from all Norwegian test sections (see Table 9-25). Furthermore the coefficient of determination (R^2) between the two is shown:

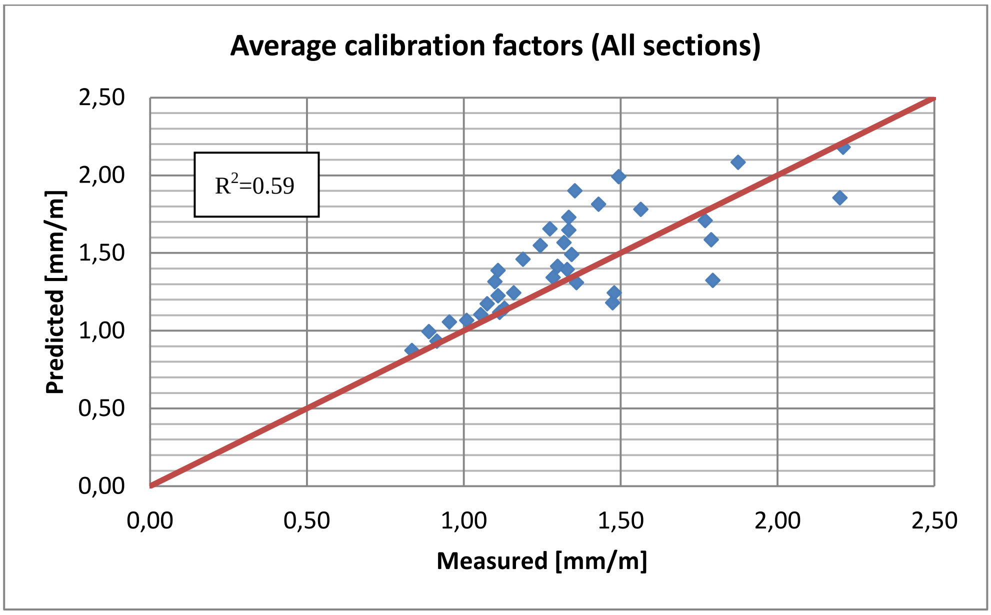

Figure 5-10. *<u>All Norwegian sections:</u> Correlation between measured and predicted roughness using average calibration factors.*

It can be seen from the figure above that there is a fair correlation between measured and predicted roughness for the Norwegian test sections using average calibration factors for all Norwegian sections. A somewhat better correlation is obtained for roughness than for rutting; this is a result of less difference between the section specific calibration factors for the different sections.

The two figures below show the measured roughness against the predicted roughness from the '3xP Nordic' software, when the Norwegian test sections are divided in high and low heavy trafficked sections (see appropriate calibration factors in Table 9-25):

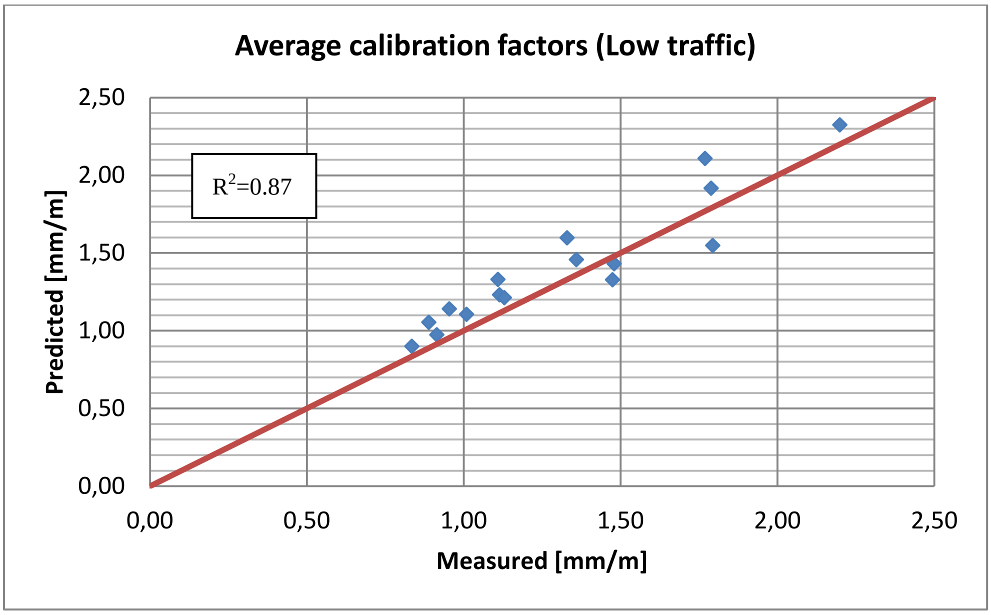

Figure 5-11. *<u>Low heavy trafficked, Norwegian sections:</u> Correlation between measured and predicted roughness using the low heavy traffic calibration factors.*

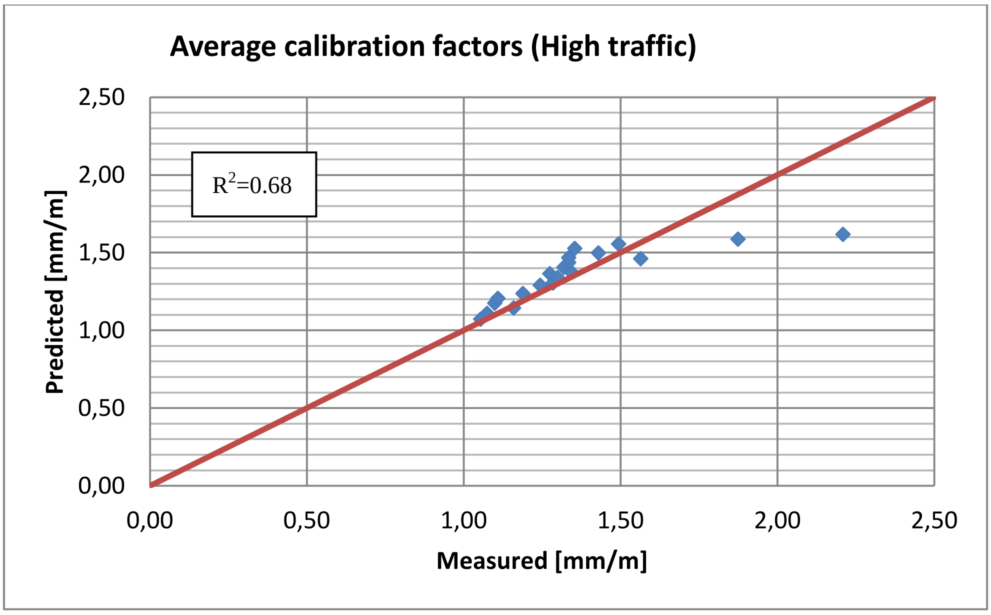

Figure 5-12. *<u>High heavy trafficked, Norwegian sections:</u> Correlation between measured and predicted roughness using the high heavy traffic calibration factors.*

From the two figures above it can be concluded that splitting the calibration factors between high and low heavy trafficked sections, the coefficient of determination correlation for roughness is improved some for the high heavy trafficked sections and significantly for and the low heavy trafficked sections (from $R^2 = 0.59$ for all sections to $R^2 = 0.68$ and $R^2 = 0.87$ for high and low heavy traffic, respectively).

5.2.3 Denmark

Validation of prediction of rutting

In figure below the measured data for rutting can be seen against the predicted development of rutting using average calibration factors from all Dansih test sections (see Table 9-25). Furthermore the coefficient of determination (R^2) between the two is shown.

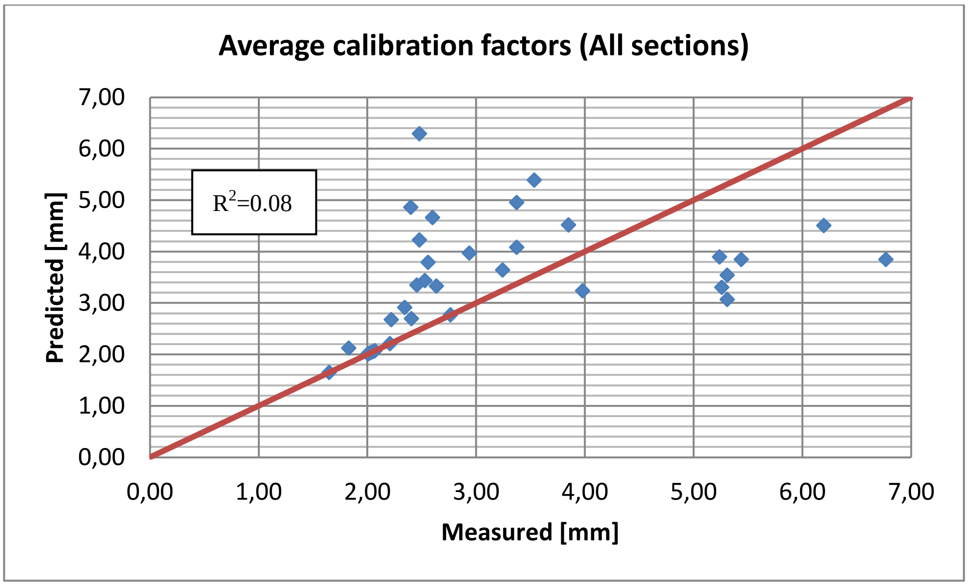

Figure 5-13. <u>All Danish sections:</u> Correlation between measured and predicted rutting using the average calibration factors.

It can be seen from the figure above that there is a very poor correlation between measured and predicted rutting for the Danish test sections using average calibration factors for all Danish sections.

The two figures below show the measured rutting against the predicted rutting from the '3xP Nordic' software, when the Danish test sections are divided in high and low heavy trafficked sections (see appropriate calibration factors in Table 9-25):

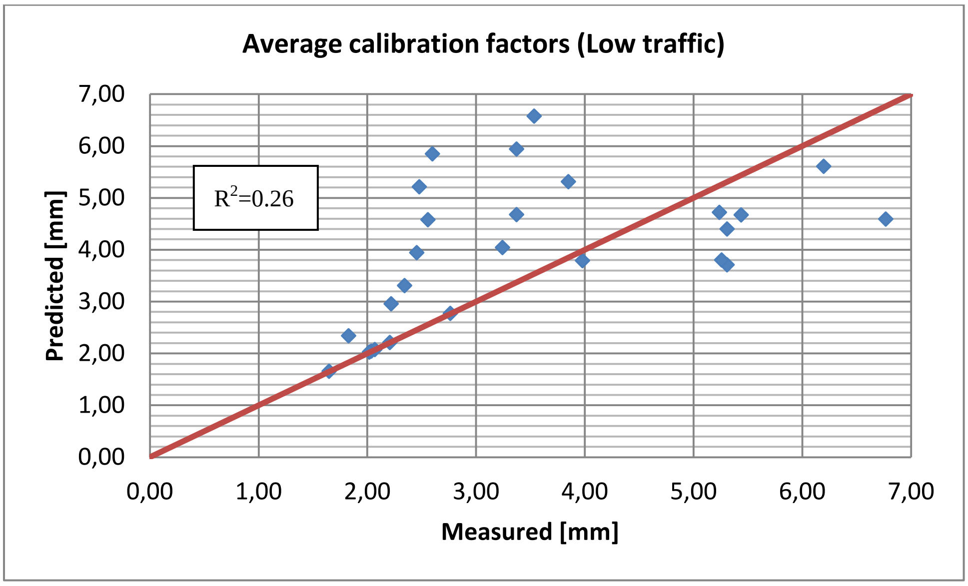

Figure 5-14. *<u>Low heavy trafficked, Danish sections:</u> Correlation between measured and predicted rutting using the low heavy traffic calibration factors.*

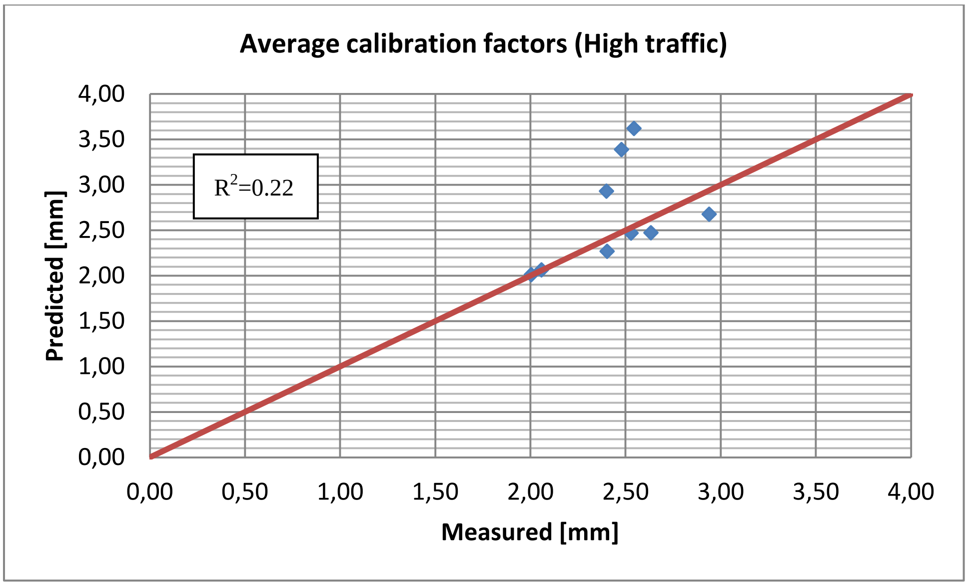

Figure 5-15. *<u>High heavy trafficked, Danish sections:</u> Correlation between measured and predicted rutting using the high heavy traffic calibration factors.*

From the two figures above it can be concluded that splitting the calibration factors between high and low heavy trafficked sections, the coefficient of determination correlation for rutting has improved some for both the high and the low heavy trafficked sections, but is not impressive (from R^2 = 0.08 for all sections to R^2 = 0.22 and R^2 = 0.26 for high and low heavy traffic, respectively).

Validation of prediction of roughness

In figure below the measured data for roughness can be seen against the predicted development of roughness using average calibration factors from all Danish test sections (see Table 9-25). Furthermore the coefficient of determination (R^2) between the two is shown:

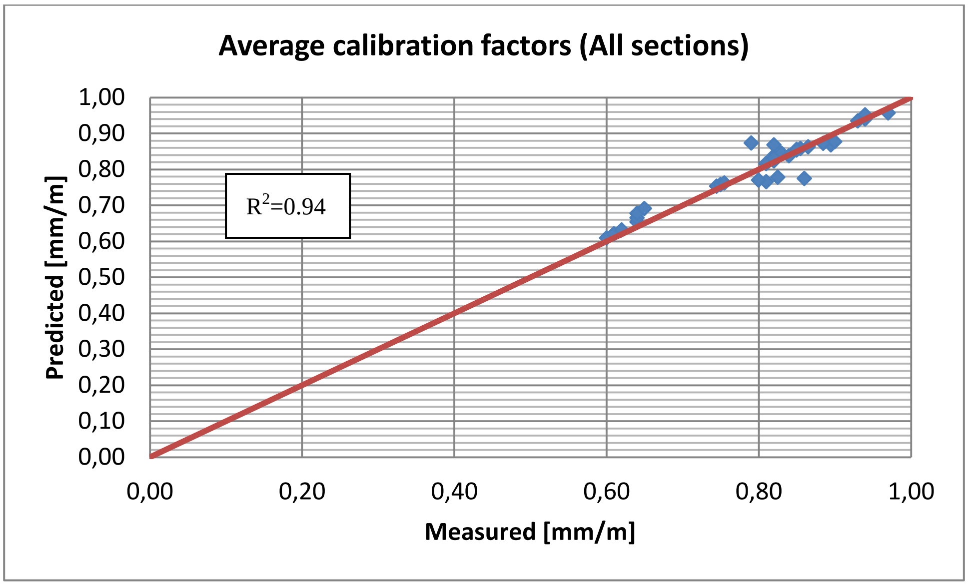

Figure 5-16. *<u>All Danish sections:</u> Correlation between measured and predicted roughness using average calibration factors.*

It can be seen from the figure above that there is a good correlation between measured and predicted roughness for the Danish test sections using average calibration factors for all Danish sections. A significantly better correlation is obtained for roughness than for rutting; this is a result of less difference between the section specific calibration factors for the different sections / subsections.

The two figures below show the measured roughness against the predicted roughness from the '3xP Nordic' software, when the Danish test sections are divided in high and low heavy trafficked sections (see appropriate calibration factors in Table 9-25):

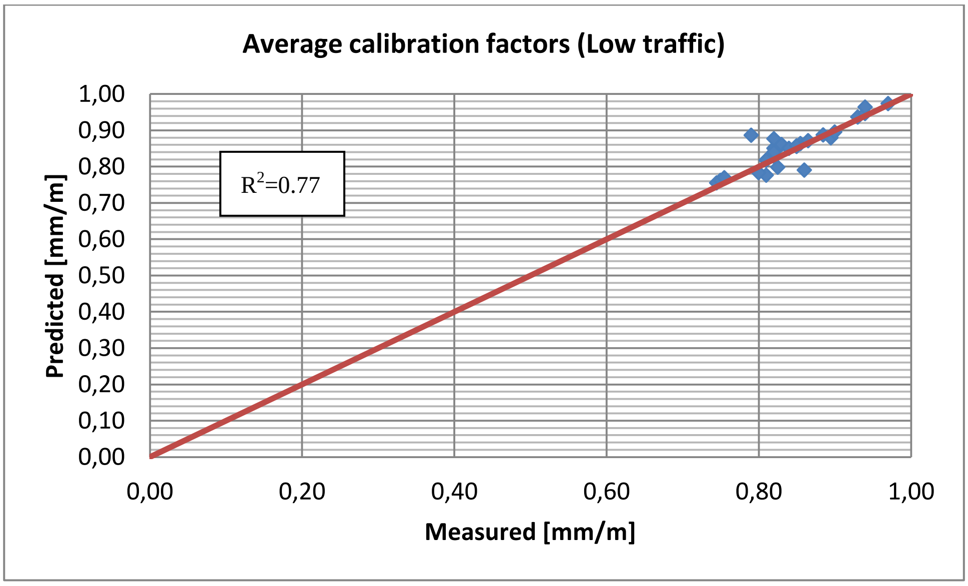

Figure 5-17. *<u>Low heavy trafficked, Danish sections:</u> Correlation between measured and predicted roughness using the low heavy traffic calibration factors.*

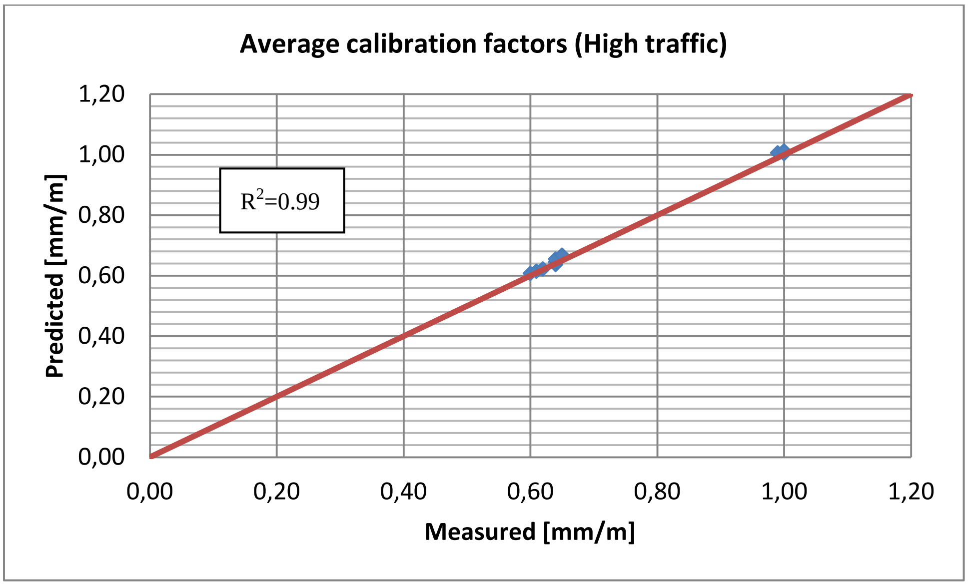

Figure 5-18. *<u>High heavy trafficked, Danish sections:</u> Correlation between measured and predicted roughness using the high heavy traffic calibration factors.*

From the two figures above it can be concluded that splitting the calibration factors between high and low heavy trafficked sections, the coefficient of determination correlation for roughness is improved for the high heavy trafficked sections and noticeably reduced for the low heavy trafficked sections (from R^2 = 0.94 for all sections to R^2 = 0.99 and R^2 = 0.77 for high and low heavy traffic, respectively).

5.3 Results of potential grouping

In the table below the R^2-values in the figures above are compiled for evaluation of the potential split in high and low heavy traffic for the three countries:

Table 5-2. *Degree of correlation with and without split in regards of heavy traffic.*

	Sweden			Norway			Denmark		
		Degree of correlation (R^2)			Degree of correlation (R^2)			Degree of correlation (R^2)	
Sections	$AADT_{heavy}$	Rutting	IRI	$AADT_{heavy}$	Rutting	IRI	$AADT_{heavy}$	Rutting	IRI
All	Full range	0.69	0.83	Full range	0.44	0.59	Full range	0.08	0.94
High	≥ 1.000	0.83	0.85	≥ 150	0.90	0.87	≥ 2.000	0.22	0.99
Low	< 1.000	0.66	0.80	< 150	0.53	0.68	< 2.000	0.26	0.77

Due to the limited historical data for the test sections in Iceland it has not been possible to determine national section specific calibration factors for Iceland. Instead section specific calibration factors calibrated for test sections in the other participating Nordic countries have been used and the accuracy of the prediction of deterioration / distress evaluated. As only roughness has been measured in more than one year on the test sections from Iceland, this is the only distress type on which the evaluation can be based.

In the figure below the measured roughness against the predicted roughness from the '3xP Nordic' software is shown, using the average calibration factors from Sweden on the two Icelandic test sections.

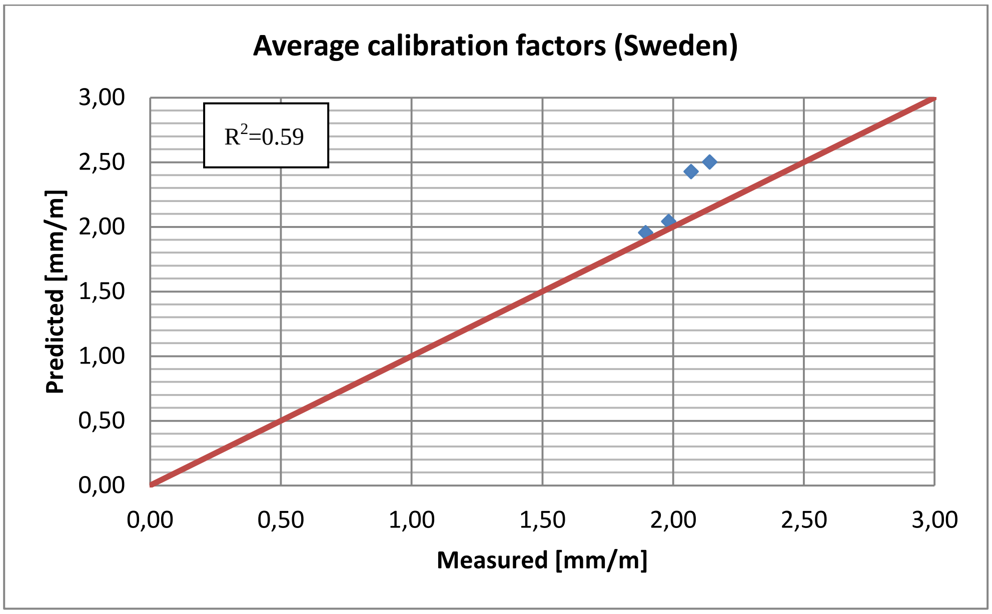

Figure 5-19. *<u>All Icelandic sections:</u> Correlation between measured and predicted roughness using average calibration factors from Sweden.*

Using calibration factors from Norway or Denmark result in a lower R2-value and thus a less accurate prediction.

From the figure above it can be seen that using the calibration factors from Sweden results in a 0.59 correlation between measured and predicted roughness. However it cannot be stressed strongly enough that this is based on a very limited amount of data, where historical data for the first year of measurement on each Icelandic test section has been used to predict the value in the next year of measurement (the two data points plotted in the figure above).

In Chapter 6 the recommendations based on the present PPM2 project is given.

6 Recommendations

6.1 Test sections

The participating countries in the PPM project is (in alphabetical order) Denmark, Iceland, Norway and Sweden.

For the PPM 2 project Sweden provided a large LTTP database with data for a great number of test sections, which had been monitored for a number of years. Not all test sections could directly be used in the PPM2 project, but the test sections with data for an adequate number of years have been used in the calibration process.

Denmark and Norway provided a very limited number of test sections; thus the reliability of the determined values in regards of section specific calibration values are limited. Iceland could only provide two test sections with data for two different years of measurement; thus it was not possible to used these two test sections for calibration of the '3xP Nordic' software.

In consequence it is recommended that Denmark and Norway provide data for more test sections in order to create more robust values for these country specific calibration factors. For Iceland it is recommended that follow-up measurements are conducted on the two test sections in the coming years; these additional measurements can either indicate if section specific calibration factors from other Nordic test sections can be used in Iceland or can even be used to determine national section specific calibration factors for Iceland.

6.2 Grouping of calibration factors

In Chapter 5 the calibration factors was grouped country wise for test sections with high and low heavy traffic, respectively, see table below:

Table 6-1. Degree of correlation with and without split in regards of heavy traffic (same as Table 5-2).

Sections	Sweden			Norway			Denmark		
	$AADT_{heavy}$	Degree of correlation (R^2)		$AADT_{heavy}$	Degree of correlation (R^2)		$AADT_{heavy}$	Degree of correlation (R^2)	
		Rutting	IRI		Rutting	IRI		Rutting	IRI
All	Full range	0.69	0.83	Full range	0.44	0.59	Full range	0.08	0.94
High	≥ 1.000	0.83	0.85	≥ 150	0.90	0.87	≥ 2.000	0.22	0.99
Low	< 1.000	0.66	0.80	< 150	0.53	0.68	< 2.000	0.26	0.77

For Sweden and Norway the degree of correlation expressed as a R^2-value generally increase for both rutting and roughness when grouping the test sections and the associated calibration factors in high and low heavy traffic.

For Denmark the prediction of rutting is poor for the full range of test sections and this is not rectified by grouping the test sections in high and low heavy traffic. For roughness the grouping in high and low heavy traffic result in a slightly better correlation for the high heavy traffic, but a worse correlation for the low heavy traffic.

In an attempt to increase the degree of correlation the average calibration factors from Sweden have been used on both the Norwegian and the Danish test sections.

The two figures below shows the measured rutting and roughness against the predicted values from the '3xP Nordic' software for the Norwegian test sections, when using the average Swedish calibration factors.

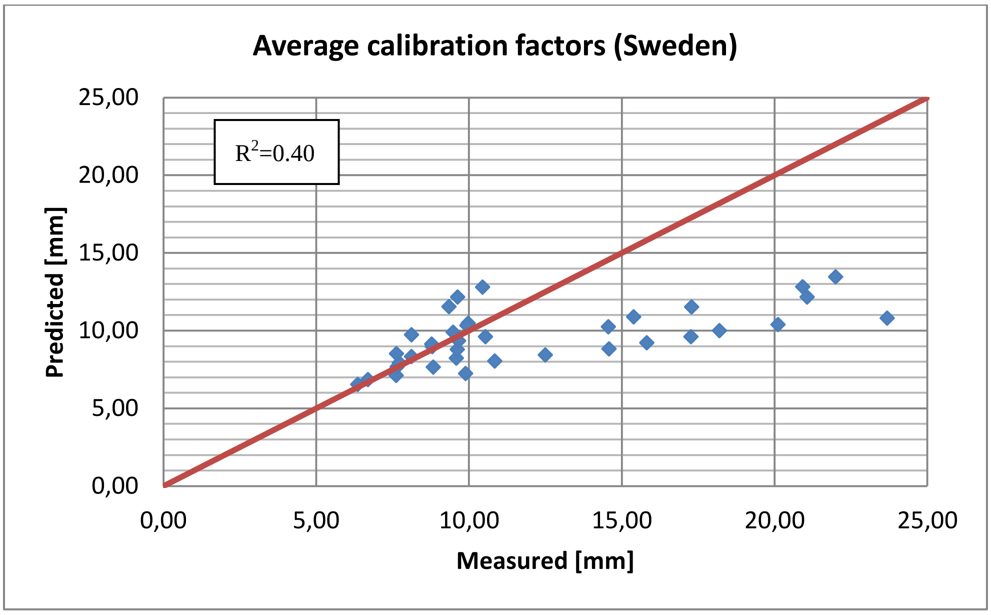

Figure 6-1. *<u>All Norwegian sections:</u> Correlation between measured and predicted rutting using average calibration factors from Sweden.*

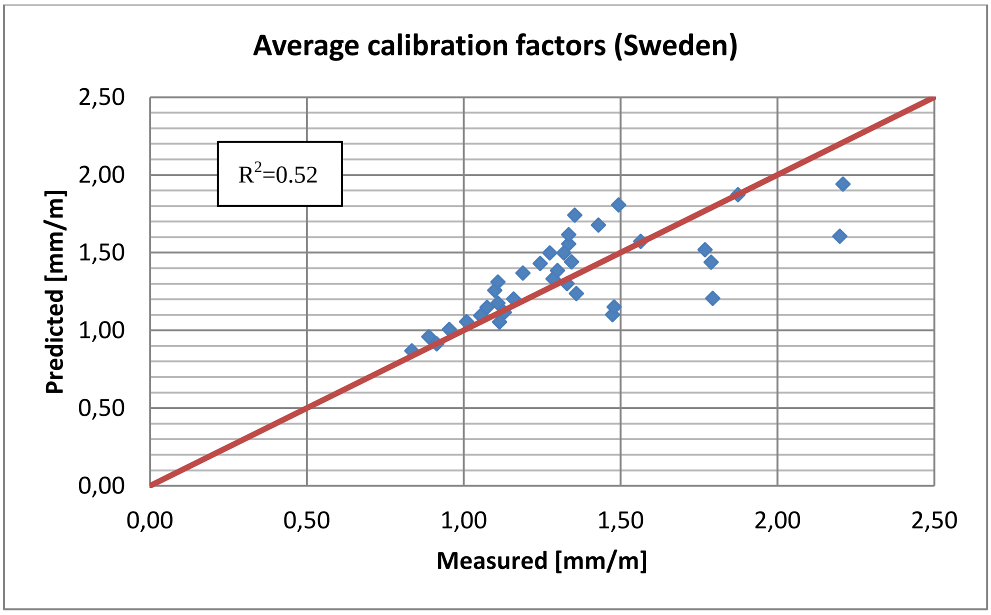

Figure 6-2. *<u>All Norwegian sections:</u> Correlation between measured and predicted roughness using average calibration factors from Sweden.*

As can be seen from the figures above using the average section specific calibration factors from Sweden does not predict neither rutting (R^2 = 0.40) nor roughness (R^2 = 0.52) as well as the Norwegian section specific calibration factors.

The two figures below shows the measured rutting and roughness against the predicted values from the '3xP Nordic' software for the Danish test sections, when using the average Swedish calibration factors.

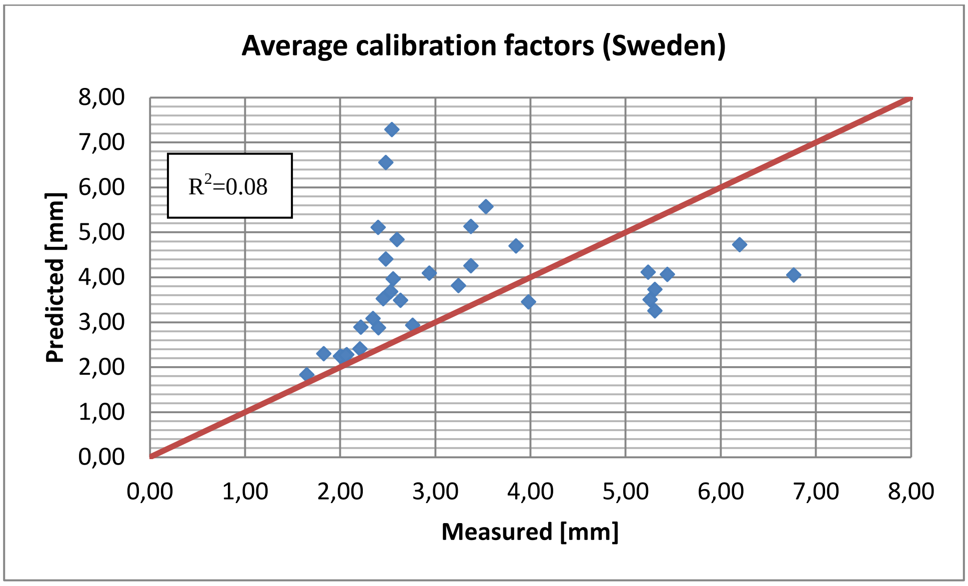

Figure 6-3. *<u>All Danish sections:</u> Correlation between measured and predicted rutting using average calibration factors from Sweden.*

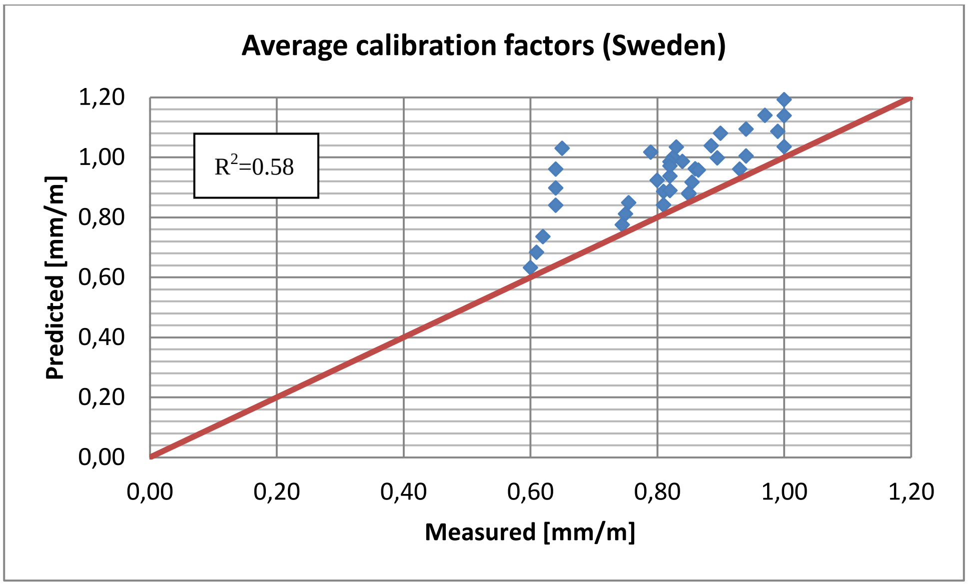

Figure 6-4. *<u>All Danish sections:</u> Correlation between measured and predicted roughness using average calibration factors from Sweden.*

As can be seen from the figures above using the average section specific calibration factors from Sweden does not predict neither rutting (R^2 = 0.08) nor roughness (R^2 = 0.58) as well as the Danish section specific calibration factors.

Thus it is recommended that the calibration factors for Sweden and Norway is grouped according to amount of heavy traffic, whereas the average values based on the full range of test sections should be used for Denmark and it should be made clear that the pavement performance models cannot be expected to provide reliable predictions for rutting. As above Denmark should provide data for more test sections in order to create more robust values for these country specific calibration factors.

This result in the following recommended calibration factors for Nordic conditions:

Table 6-2. Country wise section specific calibration factors (from Table 9-25 in Appendix F).

Calibration factor[1)]	Sweden		Norway		Denmark
	High heavy traffic (≥ 1.000)	Low heavy traffic (< 1.000)	High heavy traffic (≥ 150)	Low heavy traffic (< 150)	Average
K_{cia}	0.99	0.74	0.74	0.74	0.74
K_{pp}	0.00	0.04	0.00	0.00	0.00
K_{rid}	0.09	0.01	0.00	0.10	0.00
K_{rst}	5.66	4.85	16.00	3.40	4.82
K_{gm}	0.48	0.78	0.35	1.75	0.12
K_{gs}	1.00	1.00	1.00	1.00	1.00
K_{gc}	0.44	0.33	1.50	0.50	0.04
K_{gr}	0.69	0.83	0.35	0.75	0.04

[1)] Values for standard calibration factors can be seen in Appendix D

The split between high and low heavy traffic for Sweden and Norway is based on a limited amount of data; thus it will be useful to investigate performance of pavement structures with heavy traffic volumes both above and below the given split in order to determine an more accurate value for the split in heavy traffic.

7 Shortcomings and future works

7.1 Validation of HDM-4 deterioration models in the '3xP Nordic' software

As described in Chapter 4.2 in Ref. /3/ the MATLAB application predicted acceptable, but not exactly the same, development of cracking, rutting and roughness as the HDM-4 program.

The main differences between the '3xP Nordic' software and the HDM-4 program are identified as:

7.1.1 Initiation of cracking

The HDM-4 program operates with exact a value of time to initiation of cracking (ICA), whereas the '3xP Nordic' software rounds ICA to the nearest integer. This results in up to 63 % increase in the amount of cracking in the first year after initiation for the '3xP Nordic' software compared with the HDM-4 program, however after which the difference quickly drops to close to 0 %, see Appendix H. As the amount of cracking at the time of initiation is small, a numerical small difference will represent a large percentage difference.

A reconfiguration of the algorithm in the '3xP Nordic' software might resolve this difference in calculating ICA.

7.1.2 Calculation of K_{cia}

Similar to time to initiation of cracking described above a discrepancy was observed, when calculating the section specific calibration factor K_{cia}, see Table 9-19 in Appendix E. However in PPM2 it was not determined whether the '3xP Nordic' software does not calculate Kcia correctly or there is a discrepancy between the documentation for HDM-4 and the actual HDM-4 program in calculation of K_{cia}.

A reconfiguration of the algorithm in the '3xP Nordic' software might resolve this difference in calculating K_{cia}.

7.1.3 Duration of dry season (d)

The duration of the dry season has an impact on the calculated Structural Number (SNP), see Appendix I. The duration of the dry season is based on the moisture class and both the HDM-4 program and the '3xP Nordic' software uses a calibration factor, d, where d is the number of dry months divided by 12 months. During the analysis it was found that the input of the dry season in terms for the number of dry months divided by 12 the '3xP Nordic' software did not give the correct result in regards of SNP compared with the HDM-4 program.

This could indicate that the HDM-4 program does not use the duration of dry season d as specified in the documentation to the HDM-4 program.

The calibration factor d was therefore calibrated so the '3xP Nordic' software produced the same SNP as the HDM-4 program. Based on the findings in Appendix I a d value of 0.57 was used for all moisture classes.

Further investigations are required to solve this issue, but for the test sections in the present study the resulting difference in SNP is neglect able for roads in semi-arid climate conditions and minor in humid and sub-humid climate conditions.

7.2 Section specific calibration factors

7.2.1 Grouping to Nordic conditions

Based on the historical data from the test sections a set of weighted, average calibration factors was determined, see Table 6-2. These average calibration factors resulted in an acceptable to good correlation between the measured and predicted development of roughness and rutting for test sections in Sweden and Norway and for roughness in Denmark.

In order to validate the applicability of these average calibration factors other test sections not used in the calibration process should be modelled and analysed and compared to the historical data.

7.2.2 National values for Iceland

No appropriate section specific calibration factors for Iceland were found due to the limited data available; use of values for the other Nordic test sections might be possible, but that will require follow-up measurements on the test sections in the coming years. With sufficient data it might also be possible to determined section specific calibration factors for Iceland.

7.2.3 Effect of studded tires

In the historical data for both Norway and Iceland the percentage of vehicles with studded tires is reported.

In regards of deterioration of pavement structures it is usually the axle load, which is the critical parameter to a degree where only heavy vehicles are considered. However the effect of studded tires is increased surface wear, and as the full spectrum of vehicles might use studded tires the full traffic volume (AADT) should be used and not only the heavy vehicles ($AADT_{heavy}$).

The historical data for Iceland is too limited to have been used in the calibration process and for Norway only the $AADT_{heavy}$ has been supplied; thus in the present PPM2 it has not been possible to calibrate the pavement performance models for rutting.

If the required traffic data are supplied for the Norwegian test sections or with follow-up measurements on the Icelandic test sections in the coming year it will be possible to include the effect of studded tires. In Chapter 9.5.1 in Ref. /3/ a recommendation on how to obtain satisfactory calibration factors for the effect of studded tires is given.

8 Conclusion

Based on the findings in PPM2 the '3xP Nordic' software can be used to predict the following deterioration / distress types for flexible pavement structures in Nordic conditions:

- Rutting
- Roughness

The models for Sweden have been validated on a large number of test sections and can be used with confidence. For the other countries, limited data was available and further calibration and validation is recommended.

In the table below the section specific calibration factors are summarized:

Table 8-1. Country wise section specific calibration factors (from Table 6-2).

Calibration factor[1)]	Sweden		Norway		Denmark
	High heavy traffic (≥ 1.000)	Low heavy traffic (< 1.000)	High heavy traffic (≥ 150)	Low heavy traffic (< 150)	Average
K_{cia}	0.99	0.74	0.74	0.74	0.74
K_{pp}	0.00	0.04	0.00	0.00	0.00
K_{rid}	0.09	0.01	0.00	0.10	0.00
K_{rst}	5.66	4.85	16.00	3.40	4.82
K_{gm}	0.48	0.78	0.35	1.75	0.12
K_{gs}	1.00	1.00	1.00	1.00	1.00
K_{qc}	0.44	0.33	1.50	0.50	0.04
K_{qr}	0.69	0.83	0.35	0.75	0.04

[1)] Values for standard calibration factors can be seen in Appendix D

No appropriate section specific calibration factors for Iceland were found due to the limited data available; use of values for the other Nordic test sections might be possible, but that will require follow-up measurements on the test sections in the coming years. With sufficient data it might also be possible to determine section specific calibration factors for Iceland.

The split between high and low heavy traffic for Sweden and Norway in the table above is based on a limited amount of data; thus it will be useful to investigate performance of pavement structures with heavy traffic volumes around the given split in order to determine a more accurate value for the split in heavy traffic.

For Sweden and Norway the above section specific calibration factors can be used to predict rutting and roughness, whereas the section specific calibration factors for Denmark can be used to predict roughness.

For the section specific calibration factors in the table above it should be noted that the pavement performance models in the '3xP Nordic' software have not been calibrated for rutting due to missing information in regards of AADT for the full traffic spectrum for the Norwegian test sections, where the use of studded tires is reported.

9 References

Ref. /1/ S. Baltzer, M. Mollerup, "'3xP Nordic' User's Guide", NordFoU - Pavement Performance Models, 2013.

Ref. /2/ C. Busch, M. L. Holst, A. S. Christiansen, G. Hildebrand, S. Baltzer, "Identification and Selection of Pavement Performance Models", NordFoU - Pavement performance models, February 2010.

Ref. /3/ A. S. Christiansen, M. L. Holst, S. Baltzer, G. Hildebrand, "Development of performance measures, modelling and calibration", NordFoU - Pavement performance models, December 2010.

Ref. /4/ A. S. Christiansen, G. Hildebrand, S. Baltzer, "Implementation strategy", NordFoU - Pavement performance models, December 2010.

Ref. /5/ N-G. Göransson, "Manual till Den Svenska Nationella LTPP-Databasen", VTI, December 2009.

Appendix A Data related to test sections

The climatic conditions for each test section in Sweden can be seen in the table below:

Table 9-1. Climate conditions for each test section in Sweden.

Section	Mean Monthly Precipitation [mm]	Avg. max. temperature [C°]	Avg. min. temperature [C°]	Moisture class [-]	Temperature class [-]
E6 (F)	62	10.96	4.67	Semi-Arid	Cool
E6 (T)	69	10.96	4.67	Semi-Arid	Cool
RV31	60	9.69	2.34	Semi-Arid	Cool
RV34	50	11.37	1.79	Semi-Arid	Cool
RV46	61	9.81	1.62	Semi-Arid	Cool
RV60	50	9.17	0.87	Semi-Arid	Cool
RV71	53	8.77	-0.79	Semi-Arid	Cool
RV80	50	9.17	0.87	Semi-Arid	Cool
RV90	47	7.75	-1.86	Semi-Arid	Cool
Road 675	57	6.14	-1.37	Semi-Arid	Cool
RV35	44	10.14	2.60	Semi-Arid	Cool
RV45	60	5.24	-1.55	Semi-Arid	Cool

The climatic conditions for each test section in Norway can be seen in the table below:

Table 9-2. Climate conditions for each test section in Norway.

Section	Mean Monthly Precipitation [mm]	Avg. max. temperature [C°]	Avg. min. temperature [C°]	Moisture class [-]	Temperature class [-]
RV5	177	17.6	-0.1	Humid	Cool
E39	105	19.0	-2.7	Sub-humid	Cool
E6	71	19.3	-5.3	Sub-humid	Cool
E8	83	15.5	-6.4	Sub-humid	Cool/Freeze

The climatic conditions for each test section in Denmark can be seen in the table below:

Table 9-3. Climate conditions for each test section in Denmark.

Section	Mean Monthly Precipitation [mm]	Avg. max. temperature [C°]	Avg. min. temperature [C°]	Moisture class [-]	Temperature class [-]
M90	64.2	12.4	5.4	Semi-Arid	Cool
M64	65.3	10.7	3.7	Semi-Arid	Cool
Road 344	65.3	10.7	3.7	Semi-Arid	Cool

The climatic conditions for each test section in Iceland can be seen in the table below:

Table 9-4. Climate conditions for each test section in Iceland.

Section	Mean Monthly Precipitation [mm]	Avg. max. temperature [C°]	Avg. min. temperature [C°]	Moisture class [-]	Temperature class [-]
Road 1	44.0	8.4	0.9	Semi-Arid	Cool
Road 38	63.4	8.8	2.2	Semi-Arid	Cool

The pavement structure, traffic and subgrade strength for each test sections in Sweden can be seen in the table below:

Table 9-5. Pavement structure, traffic and subgrade strength for each test section in Sweden.

Section	ESALs per year	Subgrade strength[1)] [MPa]	Surface thickness [mm]
E6 (F)	745,283	55	235
E6 (T)	745,695	61	213
RV31	127,750	104	85
RV34	106,945	40	75
RV46	59,860	82	82
RV60	167,535	98	130
RV71	50,735	51	75
RV80	81,030	83	75
RV90	41,975	53	115
Road 675	8,030	62	50
RV35	162,425	202	105
RV45	48,910	131	138

[1)] Weighted average values for all subsections.

The pavement structure, traffic and subgrade strength for each test sections in Norway can be seen in the table below:

Table 9-6. Pavement structure, traffic and subgrade strength for each test section in Norway.

	RV5	**E39**	**E6**	**E8**
ESALs per year	33,428	33,428	326,853	83,570
Subgrade strength [MPa]	200	100	30	50
Asphalt Wearing Course [mm]	40	40	50	50
Asphalt Binder Course [mm]	40	50	80	70
Asphalt Base Course [mm]	30	-	60	-
Base Course [mm]	140	180	100	100
Sub-Base [mm]	150	140	810	700

The pavement structure, traffic and subgrade strength for each test sections in Denmark can be seen in the table below:

Table 9-7. Pavement structure, traffic and subgrade strength for each test section in Denmark.

	M90-1	M90-2	M64-1	M64-2	Road 344
ESALs per year	1,237,889	1,237,889	701,107	701,107	341,768
Subgrade strength [MPa]	40 - 70[1)]	40 - 70[1)]	100 - 150	100 - 150	172
Asphalt Wearing Course [mm]	35	36	35	35	200
Asphalt Binder Course [mm]	70	60	65	70	
Asphalt Base Course [mm]	80	140	125	95	
Macadam [mm]	130	-	-	-	-
Base Course [mm]	150	180	200	200	200
Sub-Base [mm]	470	600	550	320	400

[1)] Assumed range of the subgrade strength

The pavement structure and traffic for each test sections in Iceland can be seen in the table below:

Table 9-8. Pavement structure and traffic for each test section in Iceland.

	Road 1	Road 38
ESALs per year	406,610	80,665
Surface thickness [mm]	30	50
Centre deflection [mm]	0.542	0.849

Appendix B Standard input parameters

The input parameters in the table below are used as standard for all test sections:

Table 9-9. Standard input parameters for calibration of deterioration models to Nordic conditions.

Standard input parameter	Standard value
Vehicle fleet:	
Passenger Car Space Equivalent	1.6
Number of Wheels	8
Number of axles	2
Tyre Type	Bias-ply
Base number of recaps	1.3
Retread cost	15
Annual km	86,000
Working hours	2,050
Average life	14
Private use	0
Passengers	0
Work related passenger-trips	0
ESALF	2
Operating weight	20
New vehicle	77,500
Replacement tyre	600
Fuel	0.7
Lubricating oil	7.37
Maintenance labour	6.18
Crew wages	10.54
Annual overhead	9,200
Annual imterest	6
Passenger working time	11
Passenger non-working time	3.2
Cargo	27

Standard input parameter	Standard value
Road Network:	
Length	1
Folow direction	Two-way
Surface class	Bituminous
Road class	Primary or Trunk
Pavement type	Asphalt mix on granular base
Surface material	Asphaltic concrete
Rise + Fall	1
No. of rises + fall	1
Superelevation	2
Avg horiz curvature	3
Adral	0.1
Speed limit enforcement	1.1
Altitude	0
XNMT	1
Road side friction	1
XMT	1
Previous/old surfacing thickness	0
Texture depth	0.7
Skid restitance	0.5
Drainage	Excellent
Separate NMT lanes	Disable
Number of lanes	2
Drainage	No change in drainage effect
Relative compaction	97
ELANES	2
Replacement cost	0
Condition based	Enabled
Initial roughness	2
Terminal roughness	12

Standard input parameter	Standard value
Year asset age defined	2004
Road formation and sub-grade, replacement cost	0
Road formation and sub-grade, residual value of asset component	0
Road formation and sub-grade, useful life of asset component	10,000
Road formation and sub-grade, age of asset in year 2004	0
Road pavement layers, replacement cost	0
Road pavement layers, residual value of asset component	0
Footway, footpaths and cycle-ways, replacement cost	100
Footway, footpaths and cycle-ways, residual value of asset component	0
Footway, footpaths and cycle-ways, useful life of asset component	0
Footway, footpaths and cycle-ways, age of asset in year 2004	0
Bridges and structures, replacement cost	0
Bridges and structures, residual value of asset component	0
Bridges and structures, useful life of asset component	0
Bridges and structures, age of asset in year 2004	0
Traffic facilities, signs and road furinture, replacement cost	0
Traffic facilities, signs and road furinture, residual value of asset component	0
Traffic facilities, signs and road furinture, useful life of asset component	0
Traffic facilities, signs and road furinture, age of asset in year 2004	0

Standard input parameter	Standard value
Traffic Flow Pattern:	
Road use	Other use
Period	1
Hrs per year	8,760
Hourly volume	0.042
% of AADT	100
Speed Flow Types:	
Number of lanes	2
Road type	Two lane road
Ultimate capacity	1,400
Free-flow capacity	140
Nominal capacity	1,260
Jam speed at capacity	25
Sigma amaxr	0.65
CALVFAC	1
VDESMUL	1
Accident Classes:	
all	Enabled
All accidents	0
Climate Zones:	
Moisture index	Dependent on moisture classification
Duration of dry season	Dependent on moisture classification
Frezze index	Dependent on temperature classification
On snow covered roads	Dependent on temperature classification
On water covered roads	Dependent on temperature classification

Appendix C Section specific input parameters used in calibration process

C.1 Test sections in Sweden

In the table below the section specific input parameters for the test sections in Sweden are given:

Table 9-10. Section specific input parameters for Swedish calibration sections.

Section specific input parameter	**Unit**	**RV31 - Nässjö**	**RV34 - Målilla**	**RV46 - Trädet**	**E6 - Fastarp**	**E6 - Tvååker**	**RV60 - Borlänge**	**RV71 - Äppelbo**	**RV80 - Bjursås**	**RV90 - Sollefteå**	**Road 675 - Kaxås**	**RV35- Kvicksund**	**RV45 - Häggenås**
Carriage-way width	[m]	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Shoulder width	[m]	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Speed limit	[km/h]	90	90	90	90	90	90	90	90	90	90	90	90
Most recent surfacing thickness	[mm]	85	75	82	235	213	130	75	75	115	50	105	138
Last reconstruction or new construction	[Year]	1989	1987	1987	1996	1991	1985	1989	1989	1996	1984	1991	1993
Condition at end of year	[Year]	1993	1992	1993	1996	1992	1993	1993	1992	1999	1990	1992	1993
All structural cracking	[%]	0	0	0	0	0	0	0	0	0	0	0	0
Wide structural cracking	[%]	0	0	0	0	0	0	0	0	0	0	0	0

Section specific input paramete r	**Unit**	**RV31 - Nässjö**	**RV34 - Målilla**	**RV46 - Trädet**	**E6 - Fastarp**	**E6 - Tvååker**	**RV60 - Borlänge**	**RV71 - Äppelbo**	**RV80 - Bjursås**	**RV90 - Sollefteå**	**Road 675 - Kaxås**	**RV35- Kvicksund**	**RV45 - Häggenås**
Thermal structural cracking	[%]	0	0	0	0	0	0	0	0	0	0	0	0
Ravelled area	[%]	0	0	0	0	0	0	0	0	0	0	0	0
Number of potholes	[No./km]	0	0	0	0	0	0	0	0	0	0	0	0
Edge break area	[m^2/km]	0	0	0	0	0	0	0	0	0	0	0	0
Survey year	[Year]	1993	1992	1993	1996	1992	1993	1993	1992	1999	1990	1992	1993
Vehicle $AADT_{heavy}$	[-]	350	293	164	2,042	2,043	459	139	222	111	22	445	134
Moisture classificati on	[-]	Semi-Arid	Semi-Arid	Semi-Arid	Semi-Arid	Sub-Humid	Semi-Arid	Semi-Arid	Semi-Arid	Semi-Arid	Semi-Arid	Semi-Arid	Semi-Arid
Mean Monthly Precipitati on	[mm]	60	50	61	61.6	69	50	53	50	47	57	44	60
Temperat ure classificati on	[-]	Cool	Cool	Cool	Cool	Cool	Cool	Cool	Cool	Cool	Cool	Cool	Cool
Avg. max. temperatu re	[°C]	9.69	11.37	9.81	10.96	10.96	9.17	8.77	9.17	7.75	6.14	10.14	5.24

Section specific input parameter	**Unit**	**RV31 - Nässjö**	**RV34 - Målilla**	**RV46 - Trädet**	**E6 - Fastarp**	**E6 - Tvååker**	**RV60 - Borlänge**	**RV71 - Äppelbo**	**RV80 - Bjursås**	**RV90 - Sollefteå**	**Road 675 - Kaxås**	**RV35- Kvicksund**	**RV45 - Häggenås**
Avg. min. temperature	[°C]	2.34	1.79	1.62	4.67	4.67	0.87	-0.79	0.87	-1.86	-1.37	2.60	-1.55

In the table below the subsection specific input parameters for the test sections in Sweden are given:

Table 9-11. Subsection specific data for Swedish sections.

Section	Subsection	Rutting [mm]	Roughness [mm/m]	Centre deflection [mm]
Nässjö-RV31	01	3.82	1.09	0.297
	02	3.75	0.90	0.279
	03	3.82	0.99	0.257
	04	3.98	0.97	0.310
Målilla-RV34	01	3.73	1.04	0.444
	02	3.93	1.14	0.430
	03	4.02	1.13	0.402
	04	4.43	1.04	0.460
Trädet-RV46	01	2.45	1.37	0.317
	02	2.90	1.24	0.299
	03	3.08	1.68	0.336
	04	2.70	1.26	0.414
	05	3.40	1.39	0.372
Fastarp-E6	01	3.10	0.70	0.228
	02	2.90	0.80	0.236
	03	3.60	0.90	0.249
	04	3.10	0.80	0.196
	05	4.60	0.80	0.163
	06	2.60	0.60	0.194
	07	2.40	0.80	0.197
Tvååker-E6	01	1.10	0.65	0.169
	02	1.15	0.71	0.179
	03	1.15	0.71	0.191
	04	2.35	1.55	0.229
	05	1.95	1.06	0.214
	06	1.80	0.98	0.205

Section	Subsection	Rutting [mm]	Roughness [mm/m]	Centre deflection [mm]
Borlänge-RV60	1	2.34	3.83	0.218
	2	1.79	3.85	0.218
	3	2.99	4.33	0.225
	4	1.93	3.53	0.214
	5	2.02	5.05	0.204
	6	1.75	4.70	0.160
	7	1.81	5.20	0.196
	8	2.41	4.00	0.216
	9	1.97	4.50	0.253
	10	2.73	4.55	0.245
Äppelbo-RV71	1	2.73	1.08	0.360
	2	2.33	0.87	0.418
	3	2.15	0.87	0.375
	4	2.10	0.98	0.370
	5	2.05	1.01	0.380
	6	1.60	0.90	0.368
	7	1.90	1.07	0.360
Bjursås-RV80	1	2.33	1.49	0.376
	2	2.08	1.35	0.306
	3	1.93	1.70	0.373
	4	2.10	1.27	0.347
	5	2.55	1.25	0.325
	6	2.18	1.27	0.341
	7	2.35	1.19	0.384
	8	2.43	1.16	0.395
	9	2.43	1.01	0.276
	10	2.13	0.83	0.281
Sollefteå-RV90	1	2.60	1.02	0.299
	2	2.50	1.63	0.366
	3	2.08	1.11	0.350
	4	2.53	1.29	0.366
	5	2.40	1.36	0.428
	6	2.50	1.34	0.426
	7	2.55	1.44	0.507
	8	2.48	1.57	0.429

Section	Subsection	Rutting [mm]	Roughness [mm/m]	Centre deflection [mm]
Kaxås-Road 675	1	4.15	2.08	0.803
	2	5.40	1.87	0.849
	3	4.35	2.09	0.651
	4	4.58	2.26	0.684
	5	5.88	1.81	0.708
	6	4.40	1.94	0.805
	7	4.93	1.83	0.716
	8	5.25	1.95	0.830
	9	4.88	2.04	0.689
	10	3.58	1.73	0.502
	11	5.10	1.78	0.804
	12	5.78	2.38	0.708
Kvicksund-RV35	1	2.83	0.94	0.258
	2	2.30	0.73	0.225
	3	2.53	0.81	0.236
	4	2.60	0.87	0.249
	5	2.70	0.83	0.231
	6	2.90	1.14	0.252
	7	3.00	0.98	0.249
	8	3.18	1.10	0.259
	9	3.05	1.06	0.225
	10	2.90	1.06	0.207
	11	2.68	1.19	0.221
Häggenås-RV45	1	0.88	1.47	0.421
	2	0.98	1.57	0.416
	3	1.20	1.44	0.398
	4	1.28	1.30	0.377
	5	1.43	1.48	0.390
	6	0.93	0.85	0.341
	7	1.20	1.68	0.392
	8	1.10	1.51	0.418
	9	1.15	0.97	0.392
	10	1.15	1.16	0.350

C.2 Test sections in Norway

In the table below the section specific input parameters for the test sections in Norway are given:

Table 9-12. Section specific input parameters for test sections in Norway.

Section specific input parameter	Unit	RV5	E39	E6	E8
Carriageway width	[m]	7.5	7.5	7.5	7.5
Shoulder width	[m]	0.5	0.5	0.5	0.5
Speed limit	[km/h]	90	90	90	90
Most recent surfacing thickness	[mm]	110	90	190	120
Last reconstruction or new construction	[Year]	2001	2001	2000	2001
Calculated SNP	[mm]	5.42	5.85	9.69	5.63
Condition at end of year	[Year]	2002	2002	2001	2002
Roughness	[mm/m]	1.01	0.84	1.29	1.06
Avg. rutting	[mm]	7.73	6.37	6.70	8.13
All structural cracking	[%]	0	0	0	0
Wide structural cracking	[%]	0	0	0	0
Thermal structural cracking	[%]	0	0	0	0
Ravelled area	[%]	0	0	0	0
Number of potholes	[No./km]	0	0	0	0
Edge break area	[m^2/km]	0	0	0	0
Survey year	[Year]	2002	2002	2001	2002
Vehicle $AADT_{heavy}$	[-]	92	92	895	229
Moisture classification	[-]	Humid	Sub-Humid	Sub-Humid	Sub-Humid
Mean Monthly Precipitation	[mm]	177	105	71	83
Temperature classification	[-]	Cool	Cool	Cool	Cool/freeze
Avg. max. temperature	[°C]	17.6	19	19.3	15.5
Avg. min. temperature	[°C]	-0.1	-2.7	-5.3	-6.4

C.3 Test sections in Denmark

In the table below the section specific input parameters for the test sections in Denmark are given:

Table 9-13. Section specific input parameters for test sections in Denmark.

Section specific input parameter	**Unit**	**M90-1**	**M90-2**	**M64-1**	**M64-2**	**Road 344**
Carriageway width	[m]	7.5	7.5	7.5	7.5	7.5
Shoulder width	[m]	0.5	0.5	0.5	0.5	0.5
Speed limit	[km/h]	90	90	90	90	90
Most recent surfacing thickness	[mm]	185	236	225	200	200
Last reconstruction or new construction	[Year]	2001	2005	2007	2007	2001
Condition at end of year	[Year]	2001	2005	2007	2007	2001
All structural cracking	[%]	0	0	0	0	0
Wide structural cracking	[%]	0	0	0	0	0
Thermal structural cracking	[%]	0	0	0	0	0
Ravelled area	[%]	0	0	0	0	0
Number of potholes	[No./km]	0	0	0	0	0
Edge break area	[m^2/km]	0	0	0	0	0
Vehicle $AADT_{heavy}$	[-]	3,391	3,391	1,921	1,921	936
Moisture classification	[-]	Semi-Arid	Semi-Arid	Semi-Arid	Semi-Arid	Semi-Arid
Mean Monthly Precipitation	[mm]	64.2	54.2	65.3	65.3	65.3
Temperature classification	[-]	Cool	Cool	Cool	Cool	Cool
Avg. max. temperature	[°C]	12.4	12.4	10.7	10.7	10.7

Section specific input parameter	Unit	M90-1	M90-2	M64-1	M64-2	Road 344
Avg. min. temperature	[°C]	5.4	5.4	3.7	3.7	3.7

In the table below the subsection specific input parameters for the test sections in Denmark are given:

Table 9-14. Subsection specific data for test sections in Denmark.

Section	Subsection	Rutting [mm]	Roughness [mm/m]	Centre deflection [mm]
M90-1	1	2.01	0.60	-
M90-2	1	2.06	1.00	-
M64-1	1	2.07	0.81	0.280
	2	2.02	0.81	0.280
M64-2	1	1.65	0.93	0.197
	2	2.21	0.85	0.241
Road 344	1	2.77	0.75	0.197
	2	2.04	0.85	0.197

C.4 Test sections in Iceland

In the table below the section specific input parameters for the test sections in Iceland are given:

Table 9-15. Section specific input parameters for test sections in Iceland.

Section specific input parameter	Unit	Road 1	Road 38
Carriageway width	[m]	7.5	7.5
Shoulder width	[m]	0.5	0.5
Speed limit	[km/h]	90	90
Most recent surfacing thickness	[mm]	30	50
Last reconstruction or new construction	[Year]	2006	2002
Condition at end of year	[Year]	2005	2005
All structural cracking	[%]	0	0

Section specific input parameter	**Unit**	**Road 1**	**Road 38**
Wide structural cracking	[%]	0	0
Thermal structural cracking	[%]	0	0
Ravelled area	[%]	0	0
Number of potholes	[No./km]	0	0
Edge break area	[m^2/km]	0	0
Vehicle $AADT_{heavy}$	[-]	1,114	221
Moisture classification	[-]	Semi-Arid	Semi-Arid
Mean Monthly Precipitation	[mm]	44.0	63.4
Temperature classification	[-]	Cool	Cool
Avg. max. temperature	[°C]	8.4	8.8
Avg. min. temperature	[°C]	0.9	2.2

Appendix D Standard calibration factors

The calibration factors in the table below are used as standard for all test sections:

Table 9-16. Standard calibration factors for calibration of deterioration models to Nordic conditions.

Standard calibration factor	Standard value
CDS	1.00
CDB	0.00
CRT	0.00
RRF	1.00
K_{cpa}	1.00
K_{ciw}	1.00
K_{cpw}	1.00
K_{cit}	1.00
K_{cpt}	1.00
K_{vi}	1.00
K_{vp}	1.00
K_{pic}	1.00
K_{pir}	1.00
K_{eb}	1.00
K_{td} [2)]	1.00
K_{sfc} [2)]	1.00
K_{sfcs} [2)]	1.00
K_{rpd}	0.00
K_{drain} [2)]	1.00
K_{snpk}	1.00
K_{rsw}	1.00
K_{rds}	1.00
K_f	1.00
K_{gp}	1.00
K_{ddf} [2)]	1.00
d	0.57 [1)]

Standard calibration factor	Standard value
p	5.00
[1] Value of d determined based calibration, see Appendix I. [2] These calibration factors is not part of the 3xP Nordic programme, since texture depth, skid resistance and drainage are not part of the calibration process.	

Appendix E Calibration of section specific calibration factors

The methodology used in the calibration process for the PPM2 project is outlined in Chapter 4 and involves the following steps:

- Step 1: Determine calibration factors directly from the historical data (K_{cia})
- Step 3: Calibrate the predicted development of rutting to historical data
- Step 4: Calibrate the predicted development of roughness (IRI) to historical data

Below the calibration process in these steps is performed.

E.1 Step 1: Calibration from historical data

Calibration of K_{cia}

As described in Chapter 4.4.2 the section specific calibration factor K_{cia} can be calculated from the historical data for the test sections in Sweden from the following equation in HDM-4:

$$ICA = K_{cia} \times \left(CDS^2 \times a_0 \times EXP^{\left(a_1 \times SNP + a_2 \times \left(\frac{YE4}{SNP^2}\right)\right)} + CRT \right)$$

where: 'ICA' is the time to initiation of all structural cracking in years.

'CDS' is the construction defect rating for bituminous surfacing.

'a_x' is the layer coefficients for the materials in the pavement structure.

'SNP' is the average annual adjusted Structural Number of the pavement.

'YE4' is the annual number of ESALs (millions/lane).

'CRT' is the cracking retardation time due to maintenance in years.

In the two tables below the standard and the section specific values for calculation of K_{cia} is shown, respectively:

Table 9-17. Standard values for calculation of K_{cia}.

Parameter	Value
CDS	1.00[1)]
CRT	0.00[1)]
a_0	4.21
a_1	0.14
a_2	-17.10

[1)] From Table 9-16.

Table 9-18. Section specific values for calculation of K_{cia} (subsections without cracking have been omitted).

Section	Subsection	YE4[1)] [mill./lane]	Centre deflection, d_0[2)] [microns]	SNP[3)] [-]	Measured ICA[4)] [years]
Borlänge RV60	1	0.168	218	8.35	7
	2	0.168	218	8.35	7
	3	0.168	225	8.20	7
	4	0.168	214	8.45	7
	5	0.168	204	8.70	7
	6	0.168	160	10.16	6
	7	0.168	196	8.93	7
	8	0.168	216	8.40	6
	9	0.168	253	7.60	6
	10	0.168	245	7.77	7
Äppelbo RV71	1	0.051	360	6.09	12
	2	0.051	418	5.54	12
	4	0.051	370	6.00	16
	5	0.051	380	5.89	16
	6	0.051	368	6.01	16

Section	Subsection	YE4[1)] [mill./lane]	Centre deflection, d_0[2)] [microns]	SNP[3)] [-]	Measured ICA[4)] [years]
Bjursås RV80	1	0.081	376	5.93	4
	2	0.081	306	6.75	4
	3	0.081	373	5.95	4
	4	0.081	347	6.23	4
	5	0.081	325	6.49	6
	6	0.081	341	6.31	5
	7	0.081	384	5.85	5
	8	0.081	395	5.74	5
	9	0.081	276	7.20	8
	10	0.081	281	7.13	6
Sollefteå RV90	1	0.041	299	6.84	9
	2	0.041	366	6.03	3
	3	0.041	350	6.20	7
	4	0.041	366	6.03	5
	5	0.041	428	5.47	4
	6	0.041	426	5.48	3
	7	0.041	507	4.91	3
	8	0.041	429	5.46	3
Nässjö RV31	1	0.128	297	6.87	10
	2	0.128	279	7.11	13.5
	3	0.128	257	7.63	11.2
	4	0.128	310	6.65	8
Målilla RV34	1	0.107	444	5.34	6
	2	0.107	430	5.45	8
	3	0.107	402	5.68	6
	4	0.107	460	5.22	6

Section	Subsection	YE4[1)] [mill./lane]	Centre deflection, d_0[2)] [microns]	SNP[3)] [-]	Measured ICA[4)] [years]
Trädet RV46	1	0.060	317	6.00	10
	2	0.060	299	6.85	11
	3	0.060	336	6.36	8
	4	0.060	414	5.58	8
	5	0.060	372	5.96	8
Tvååker E6	1	0.764	169	9.81	12
	2	0.764	179	9.46	12
	3	0.764	191	9.07	12
	4	0.764	229	8.11	13
	5	0.764	214	8.46	13
	6	0.764	205	8.68	13
Kvicksund RV35	1	0.162	258	7.51	4
	2	0.162	225	8.18	4
	3	0.162	236	7.94	6
	4	0.162	249	7.69	4
	5	0.162	231	8.06	6
	6	0.162	252	7.63	4
	7	0.162	249	7.68	4
	8	0.162	259	7.49	4
	9	0.162	225	8.19	5
	10	0.162	207	8.64	5
	11	0.162	221	8.29	4

Section	Subsection	YE4[1)] [mill./lane]	Centre deflection, d_0[2)] [microns]	SNP[3)] [-]	Measured ICA[4)] [years]
Häggenås RV45	1	0.049	421	5.52	5
	2	0.049	416	5.56	3
	3	0.049	398	5.72	2
	4	0.049	377	5.92	2
	5	0.049	390	5.80	2
	6	0.049	341	6.31	5
	7	0.049	392	5.77	5
	8	0.049	418	5.54	9
	9	0.049	392	5.78	9
	10	0.049	350	6.20	5

[1)] Value from Table 9-5 divided by 1,000,000 to convert to correct unit.

[2)] Value from Table 9-11 multiplied by 1,000 to convert to correct unit.

[3)] The Structural Number (SNP) can be determined based on e.g. Falling Weight Deflectometer (FWD) measurements as:

$$SNP = 3.2 \times \left(\frac{d_0}{1.000}\right)^{-0.63}$$

where: 'd_0' is the centre deflection in microns.

[4)] From historical data.

Based on the values in the two tables above K_{cia} can be calculated, see table below.

However using these calculated values in the '3xP Nordic' software does not result in the correct year for initiation of cracking compared to the historical data. Thus using the calculated value as basis K_{cia} has been calibrated to match the time to initiation of cracking from the historical data and in the table below both the calculated and the calibrated values for K_{cia} can be seen:

Table 9-19. Calculated and calibrated values of K_{cia}.

Section	Subsection	Calculated K_{cia}	Calibrated K_{cia}	Difference [%]
Borlänge RV60	1	0.54	0.50	7.41
	2	0.54	0.43	20.37
	3	0.55	0.51	7.27
	4	0.53	0.50	5.66
	5	0.51	0.48	5.88
	6	0.36	0.32	9.86
	7	0.49	0.46	6.12
	8	0.46	0.42	8.70
	9	0.52	0.48	7.69
	10	0.59	0.55	6.78
Äppelbo RV71	1	1.24	1.20	3.23
	2	1.35	1.30	3.70
	4	1.68	1.64	2.38
	5	1.71	1.67	2.34
	6	1.68	1.64	2.38
Bjursås RV80	1	0.43	0.38	11.63
	2	0.38	0.33	13.16
	3	0.43	0.38	11.63
	4	0.41	0.36	12.20
	5	0.59	0.55	6.78
	6	0.51	0.46	9.80
	7	0.54	0.49	9.26
	8	0.55	0.50	9.09
	9	0.71	0.67	5.63
	10	0.54	0.50	7.41

Section	Subsection	Calculated K_{cia}	Calibrated K_{cia}	Difference [%]
Sollefteå RV90	1	0.83	0.79	4.82
	2	0.31	0.26	16.13
	3	0.71	0.66	7.04
	4	0.52	0.47	9.62
	5	0.45	0.39	13.33
	6	0.34	0.28	17.65
	7	0.37	0.31	16.22
	8	0.34	0.28	17.65
Nässjö RV31	1	0.95	0.87	8.65
	2	1.24	1.24	0.00
	3	0.95	0.90	5.61
	4	0.79	0.70	11.02
Målilla RV34	1	0.72	0.65	9.69
	2	0.94	0.85	9.80
	3	0.68	0.60	11.91
	4	0.73	0.65	11.42
Trädet RV46	1	0.93	0.90	3.80
	2	0.98	0.98	0.00
	3	0.80	0.76	5.26
	4	0.90	0.85	5.79
	5	0.85	0.80	6.07
Tvååker E6	1	0.83	0.81	2.07
	2	0.88	0.86	1.99
	3	0.94	0.91	2.97
	4	1.21	1.18	2.53
	5	1.13	1.10	3.04
	6	1.09	1.06	2.64

Section	Subsection	Calculated K_{cia}	Calibrated K_{cia}	Difference [%]
Kvicksund RV35	1	0.34	0.30	11.76
	2	0.31	0.27	12.90
	3	0.48	0.45	5.26
	4	0.33	0.30	9.09
	5	0.47	0.47	0.00
	6	0.33	0.30	9.09
	7	0.33	0.30	9.09
	8	0.34	0.31	8.82
	9	0.38	0.35	7.89
	10	0.36	0.33	8.33
	11	0.30	0.27	10.00
Häggenås RV45	1	0.56	0.51	8.93
	2	0.34	0.28	17.65
	3	0.22	0.16	27.27
	4	0.21	0.16	23.81
	5	0.22	0.16	27.27
	6	0.50	0.45	10.00
	7	0.54	0.49	9.26
	8	1.01	0.96	4.95
	9	0.98	0.93	5.10
	10	0.51	0.46	9.80
Cells with grey background are NOT used in the following calibration process.				

As can be seen from the table above the difference between the calculated and the calibrated values of K_{cia} range from 0% to close to 30% with an average of 8.75%.

However using the values in Table 9-17 and Table 9-18 in the HDM-4 program result in values given in Table 9-19 under the heading 'Calculated K_{cia}'; thus either the '3xP Nordic' software does not calculate Kcia correctly or there is a discrepancy between the documentation for HDM-4 and the actual program in calculation of K_{cia}.

The above section specific calibration factors are also included in Table 9-22 at the end of this appendix.

Calibration of K_{rid}

As described in Chapter 4.4.2 the section specific calibration factor K_{rid} cannot be determined from the historical data as the rutting has not been measured early after construction (e.g. year 0 and year 1). Thus K_{rid} has been calculated as a best fit based on the historical data; the resulting values are summarised in Table 9-22 in the end of this appendix.

E.2 Step 3: Calibration of rutting

The following section specific calibration factors are related to rutting in the HDM-4 deterioration models; the list below is ranked according to effect on rutting:

- K_{rst} (Calibration factor for the rutting structural deterioration model)
- K_{rpd} (Calibration factor for the rutting plastic deformation model)

On the LTPP test sections rutting has been registered; however it is not reported how much of the total rutting is due to structural deformation (related to K_{rst}) and how much is due to plastic deformation (related to K_{rpd}).

In the present project at network level it is assumed that the plastic deformation of the asphalt on highways and main roads in the Nordic contries is relatively low and thus the effect from this distess function is neglected by assigning the default value in the HDM-4 program to K_{rpd}.

In the two figures below representative examples of comparisons of historical data for rutting (square dots) and the calibrated development of rutting from the '3xP Nordic' software (full lines) are illustrated.

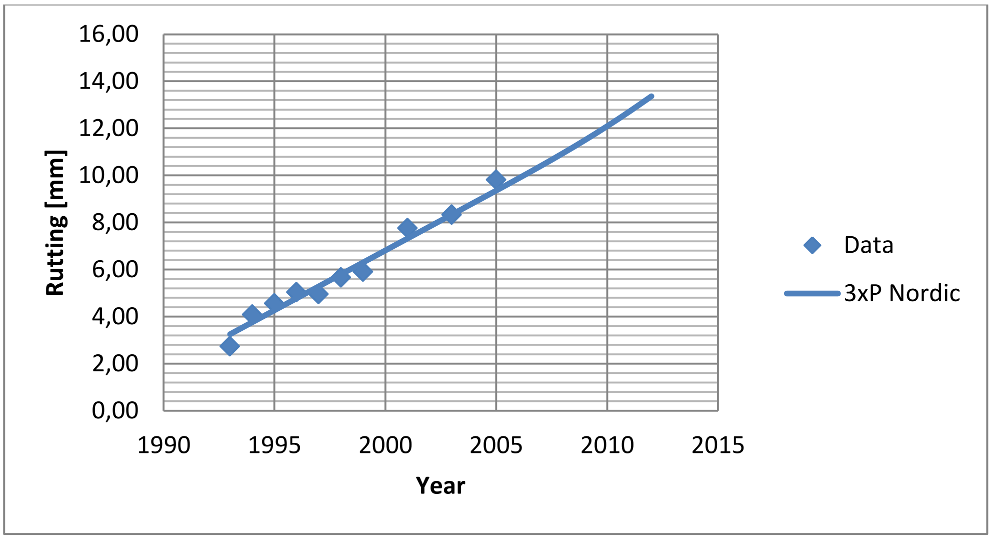

Figure 9-1. Historical data for rutting and calibrated prediction of rutting from the '3xP Nordic' software for Äppelbo (RV71), subsection 1, Sweden.

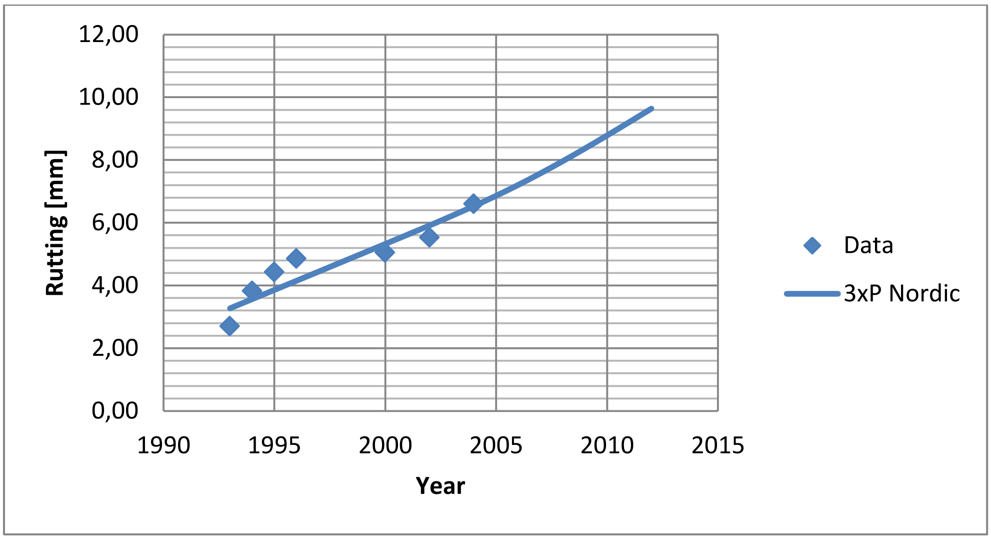

Figure 9-2. *Historical data for rutting and calibrated prediction of rutting from the '3xP Nordic' software for Trädet (RV46), subsection 4, Sweden.*

In the two figures above representative examples of comparisons between measured and predicted rutting are shown. In Figure 9-3 to Figure 9-16 the correlation between prediction of rutting has been compared with the measured, historical data in regards of rutting for each section calibrated in this project.

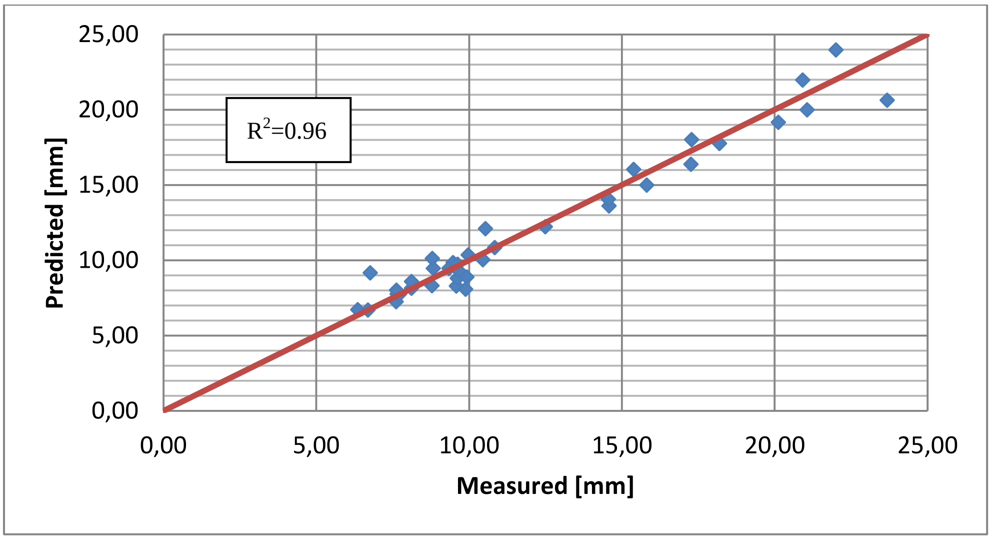

Figure 9-3. *Correlation between measured and predicted rutting (All Norwegian sections).*

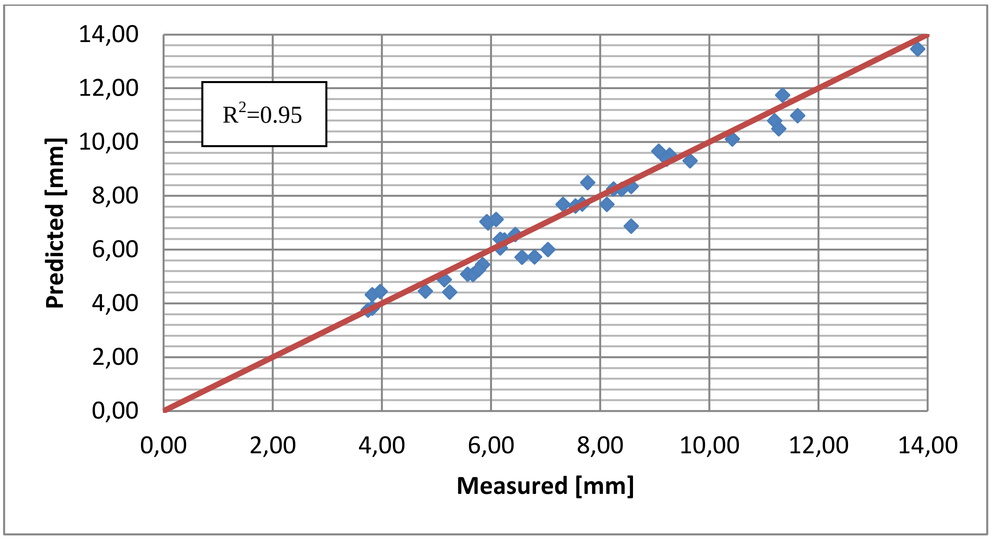

Figure 9-4. Correlation between measured and predicted rutting, Nässjö (RV31), Sweden.

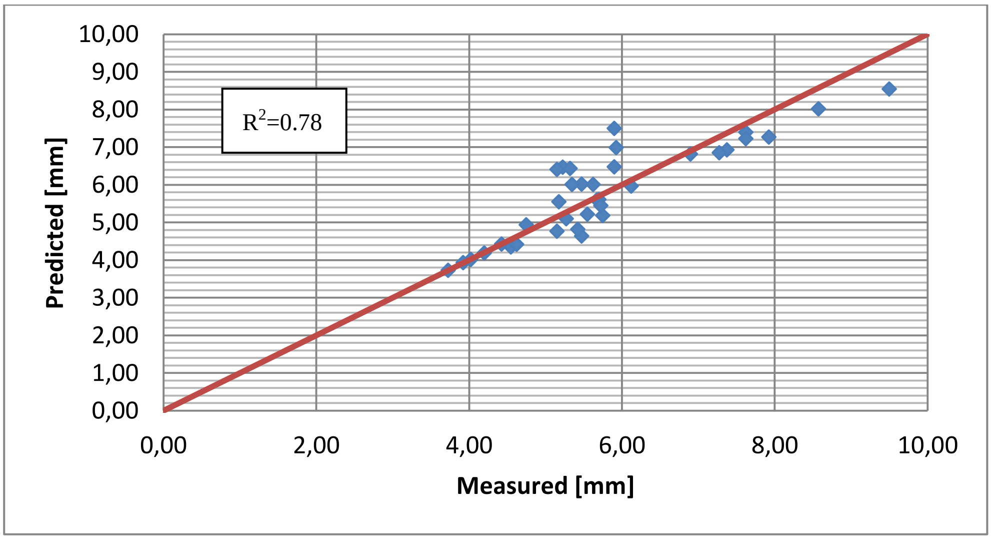

Figure 9-5. Correlation between measured and predicted rutting, Målilla (RV34), Sweden.

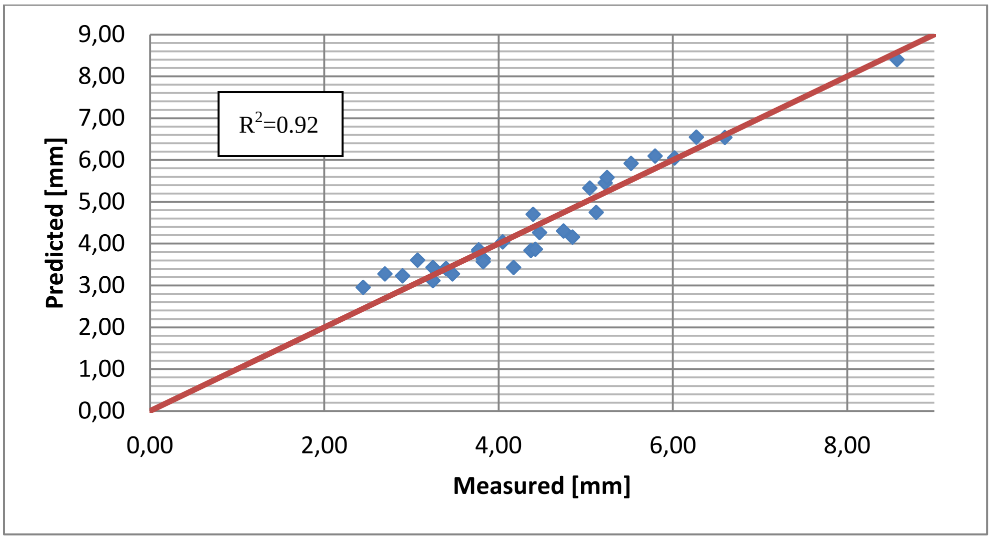

Figure 9-6. Correlation between measured and predicted rutting, Trädet (RV46), Sweden.

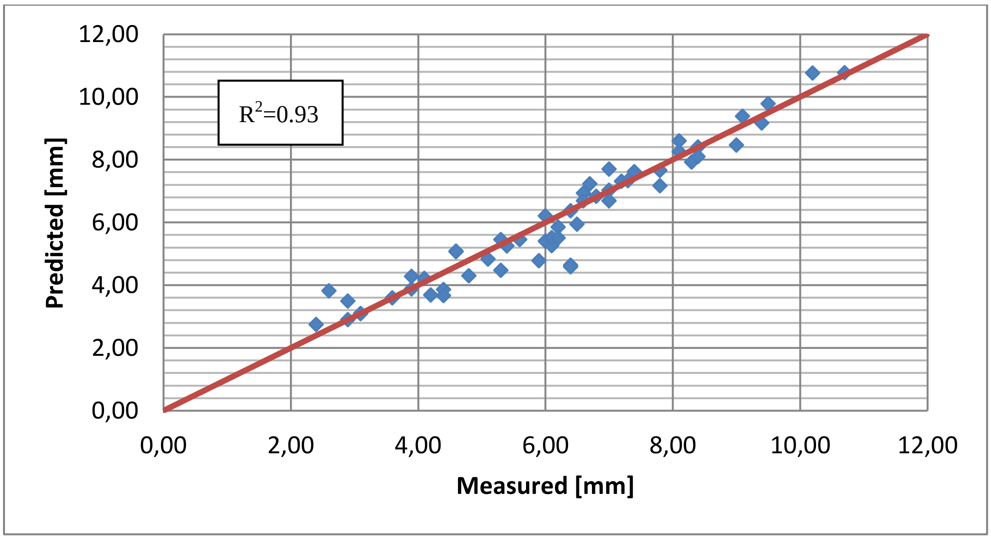

Figure 9-7. Correlation between measured and predicted rutting, Fastarp (E6), Sweden.

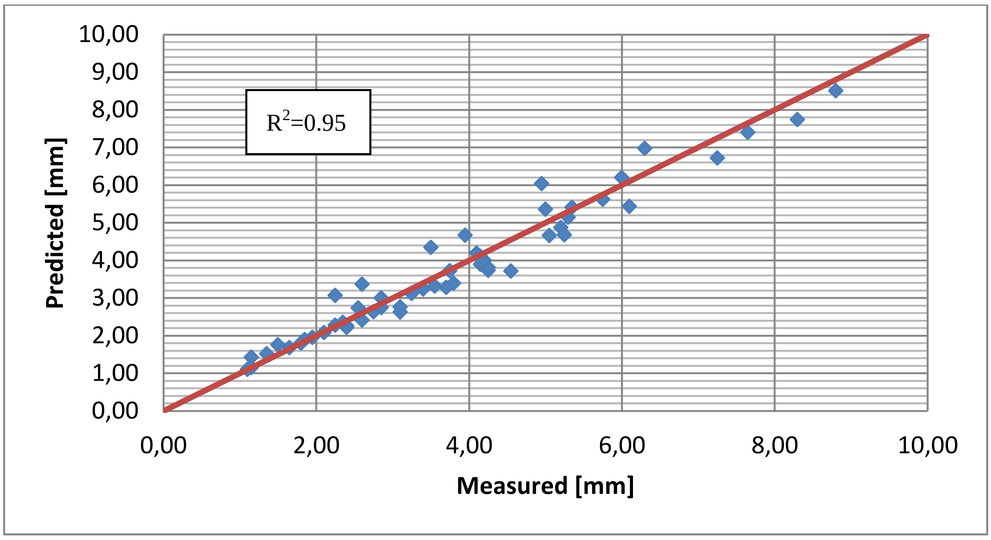

Figure 9-8. Correlation between measured and predicted rutting, Tvååker (E6), Sweden.

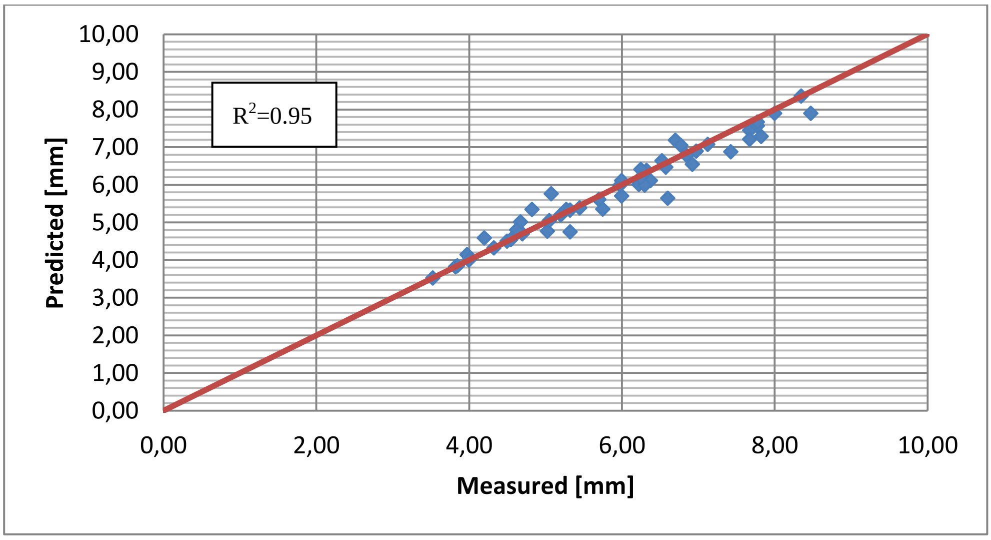

Figure 9-9. Correlation between measured and predicted rutting, Borlänge (RV60), Sweden.

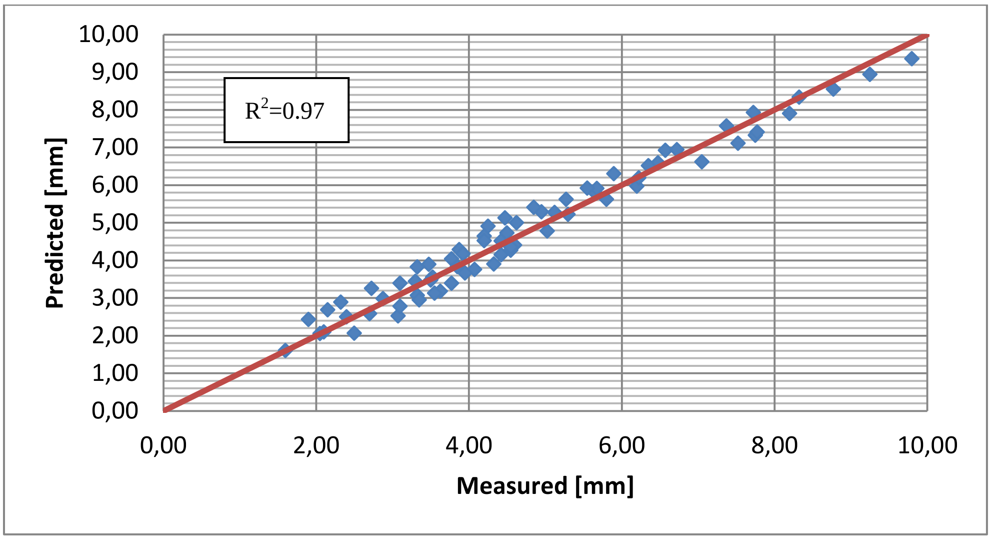

Figure 9-10. Correlation between measured and predicted rutting, Äppelbo (RV71), Sweden.

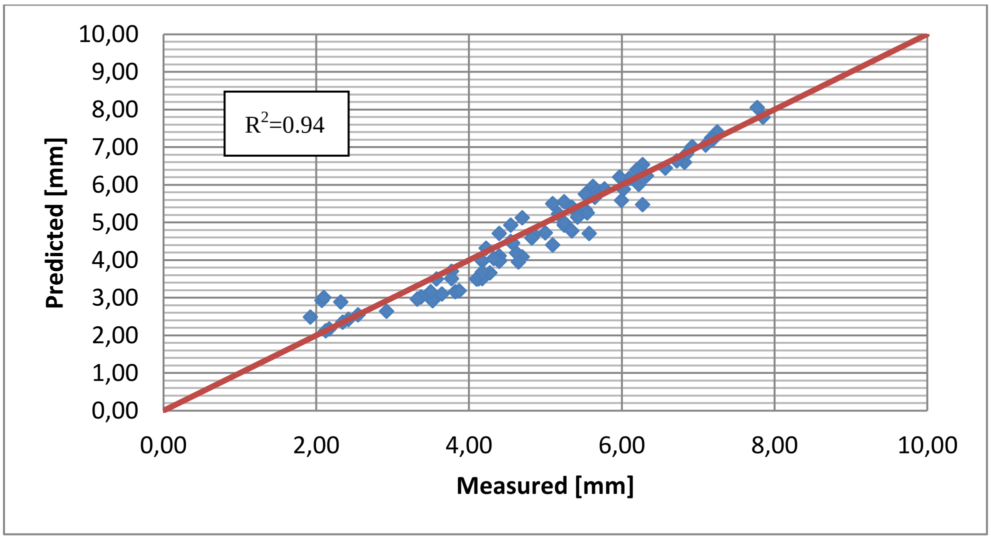

Figure 9-11. Correlation between measured and predicted rutting, Bjursås (RV80), Sweden.

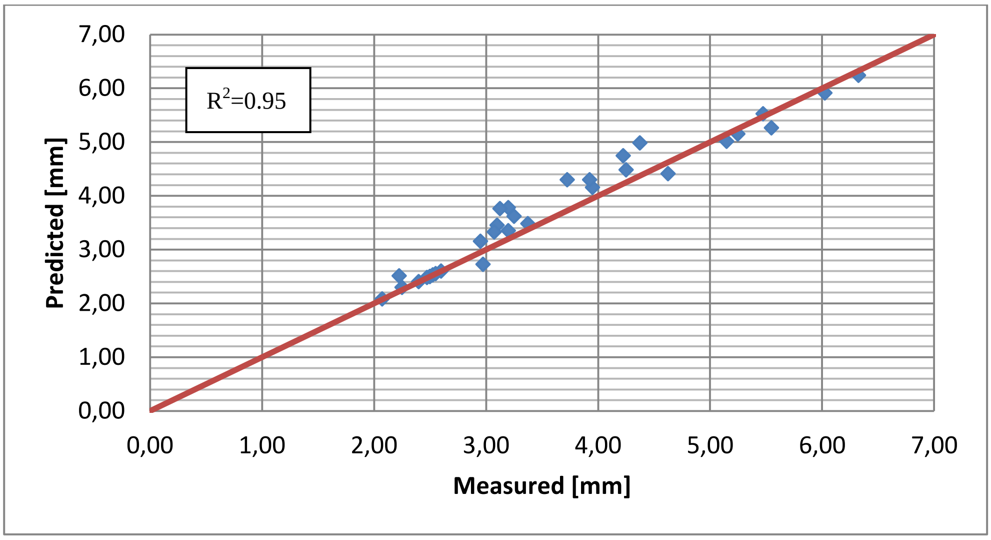

Figure 9-12. Correlation between measured and predicted rutting, Sollefteå (RV90), Sweden.

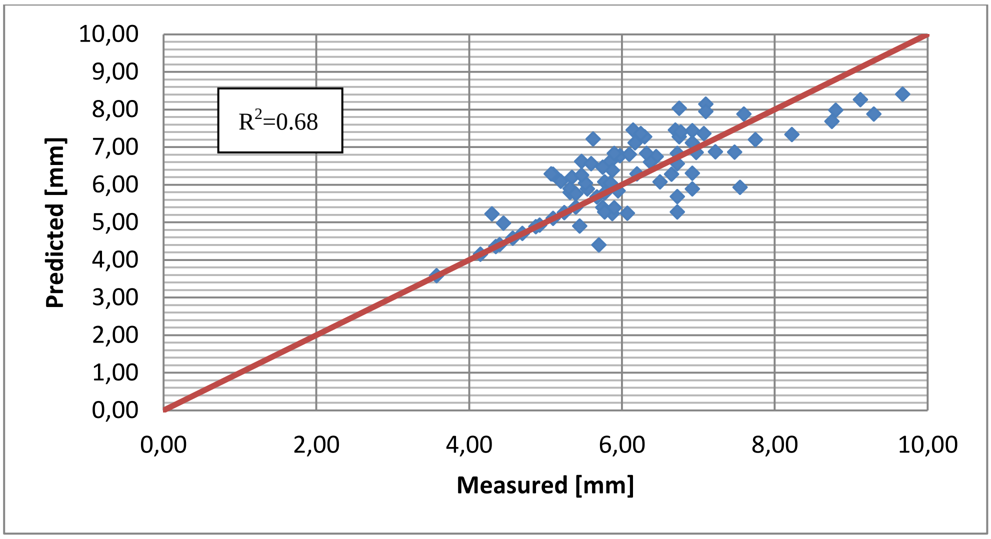

Figure 9-13. Correlation between measured and predicted rutting, Kaxås (Road 675), Sweden.

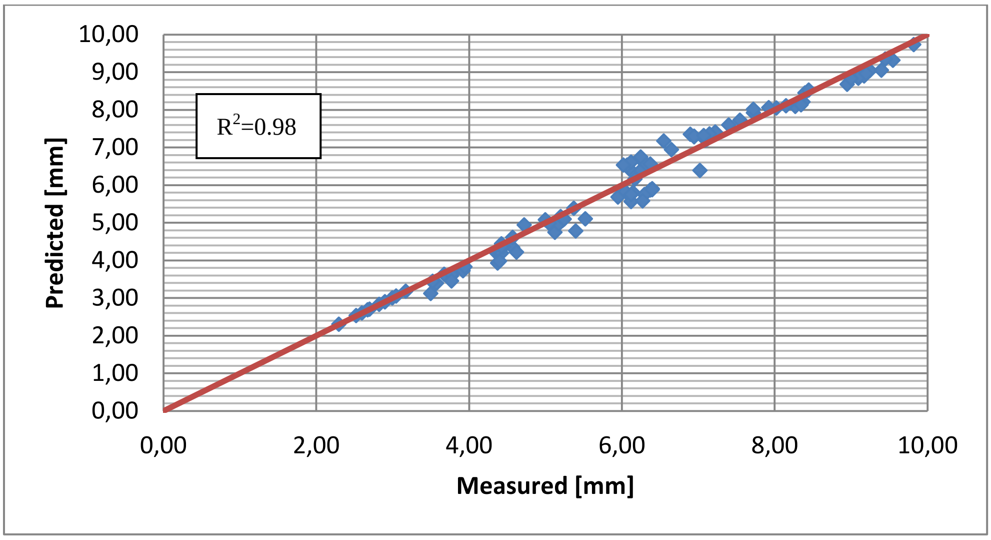

Figure 9-14. Correlation between measured and predicted rutting, Kvicksund (RV35), Sweden.

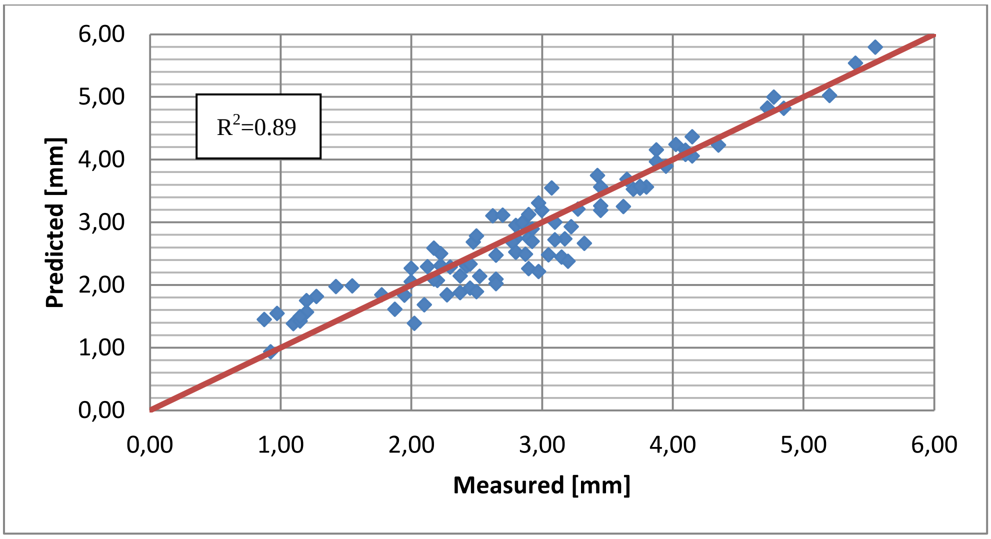

Figure 9-15. Correlation between measured and predicted rutting, Häggenås (RV45), Sweden.

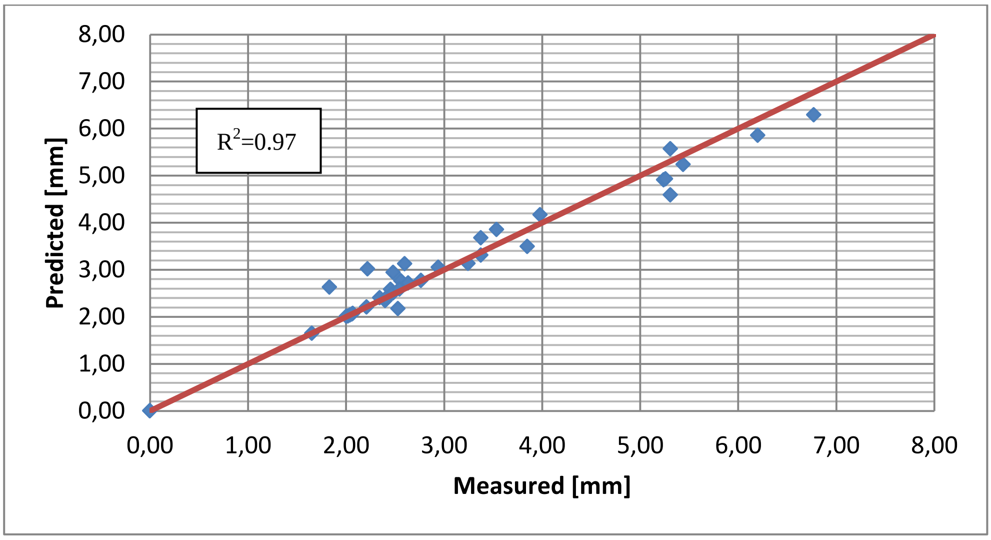

Figure 9-16. Correlation between measured and predicted rutting (All Danish sections).

In the table below the degree of correlation (R^2-value) for the rutting is summarised for Figure 9-3 to Figure 9-16:

Table 9-20. Degree of correlation between measured and predicted rutting.

Section	R^2-value for rutting
All Norwegian	0.96
Nässjö (RV31)	0.95
Målilla (RV34)	0.78
Trädet (RV46)	0.92
Fastarp (E6)	0.93
Tvååker (E6)	0.95
Borlänge (RV60	0.95
Äppelbo (RV71)	0.97
Bjursås (RV80)	0.94
Sollefteå (RV90)	0.95
Kaxås (Road 675)	0.68
Kvicksund (RV35)	0.98
Häggenås (RV45)	0.89
All Danish	0.97

It can be seen from the table above that there is a good correlation (R^2-value close to '1') between the measured and the predicted rutting on the calibrated sections.

The used section specific calibration factors are included in Table 9-22 at the end of this appendix.

E.3 Step 4: Calibration of roughness

The following section specific calibration factors are related to roughness in the HDM-4 deterioration models; the list below is ranked according to effect on roughness:

- K_{gm} (Calibration factor for the environmental roughness model)
- K_{gc} (Calibration factor for the roughness model (cracking contribution))
- K_{gr} (Calibration factor for the roughness model (ravelling contribution))
- K_{gp} (Calibration factor for the roughness model (pothole contribution))
- K_{gs} (Calibration factor for the roughness model (structural contribution))
- K_{rds} (Calibration factor for the rut depth standard deviation model)
- K_{pp} (Calibration factor for the pothole progression model)
- K_{pic} (Calibration factor for the pothole initiation due to the cracking model)
- CDB (Construction defects indicator for the base)
- K_{snpk} (Calibration factor for change in adjusted Structural Number due to cracking)

In the two figures below representative exampels of comparisons of historical data for roughness expressed as IRI (square dots) and the calibrated development of IRI from the '3xP Nordic' software (full lines) are illustrated.

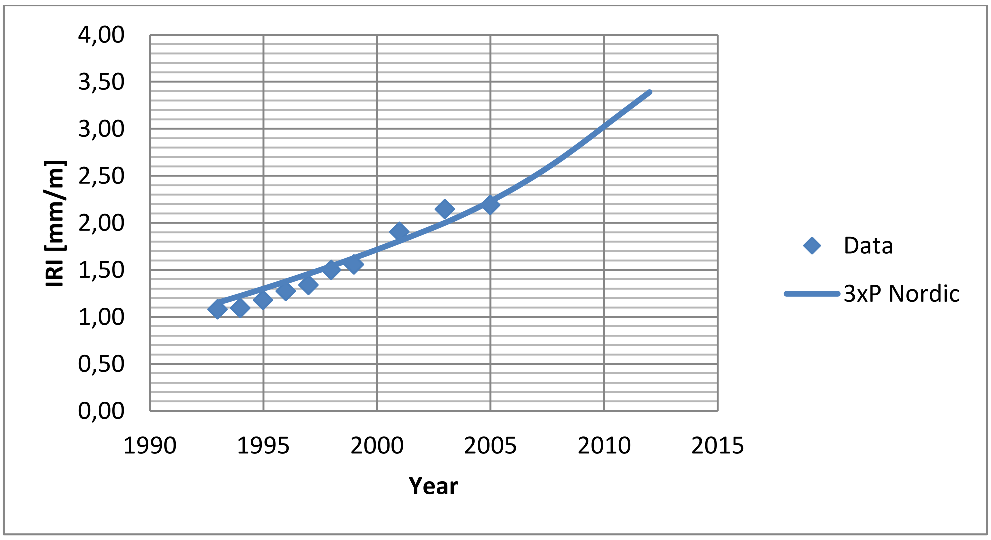

Figure 9-17. Historical data for IRI and calibrated prediction of IRI from the '3xP Nordic' software for Äppelbo (RV71), subsection 1, Sweden.

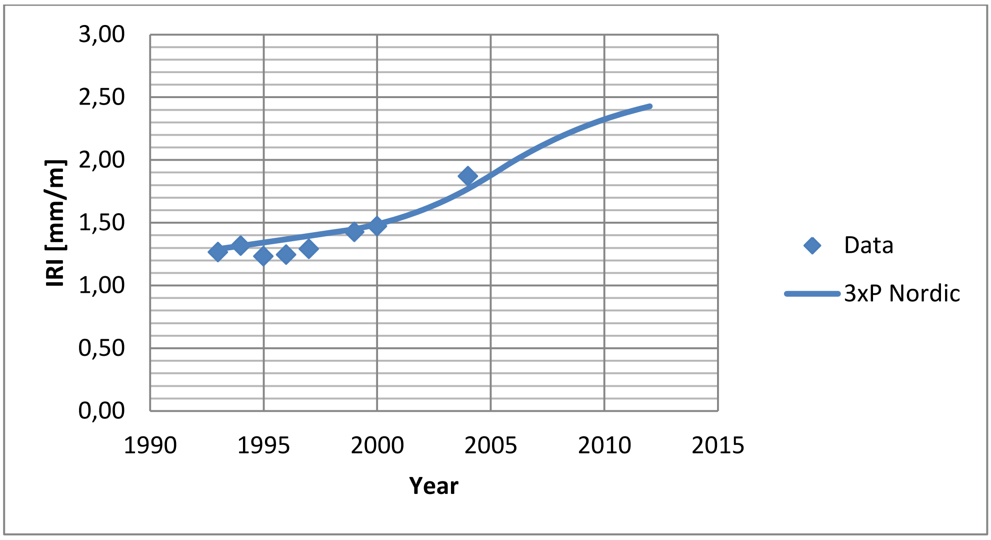

Figure 9-18. Historical data for IRI and calibrated prediction of IRI from the '3xP Nordic' software for Trädet (RV46), subsection 4, Sweden.

In the two figures above representative examples of comparisons between measured and predicted roughness expressed as IRI are shown. In Figure 9-19 to Figure 9-32 the correlation between prediction of IRI has been compared with the measured, historical data in regards of IRI for each section calibrated in this project.

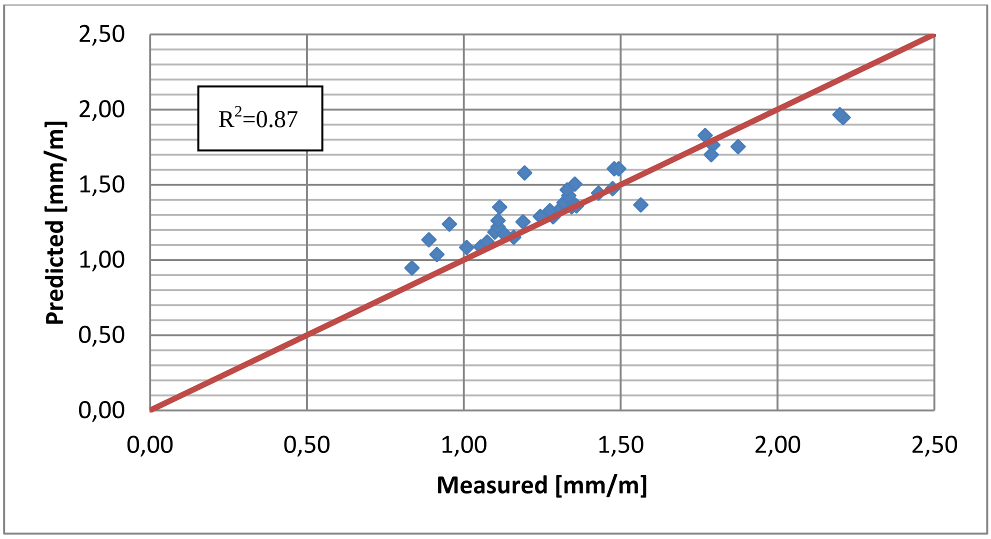

Figure 9-19. Correlation between measured and predicted IRI (All Norwegian sections).

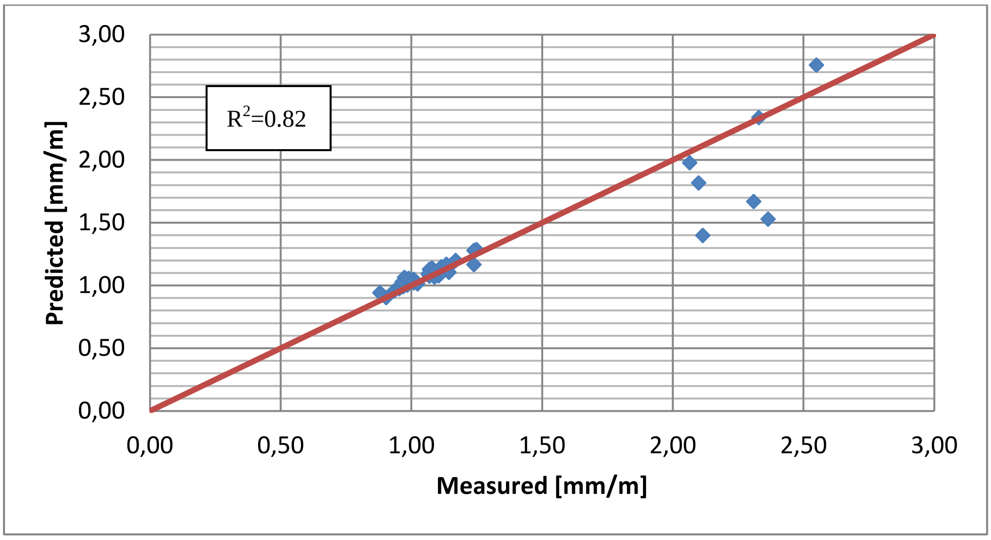

Figure 9-20. Correlation between measured and predicted IRI, Nässjö (RV31), Sweden.

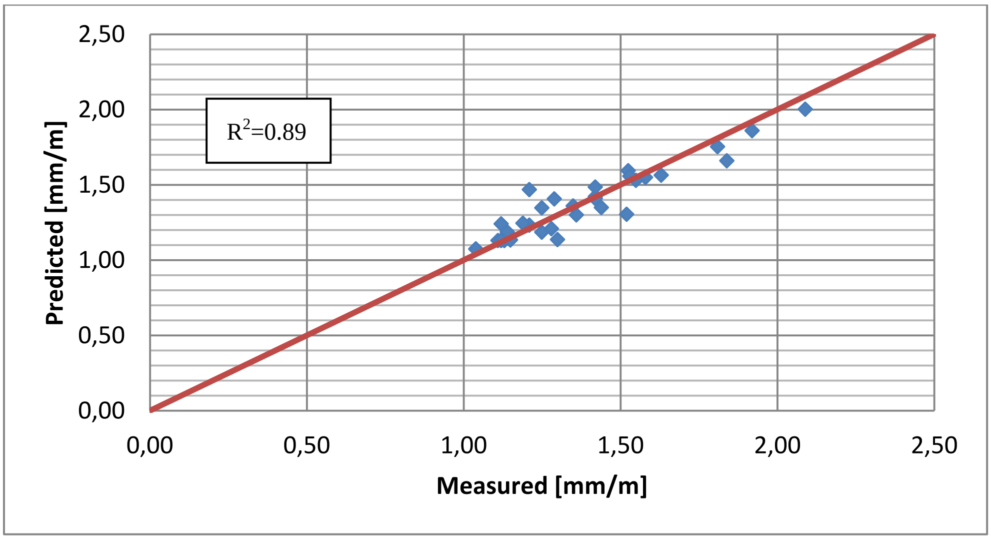

Figure 9-21. Correlation between measured and predicted IRI, Målilla (RV34), Sweden.

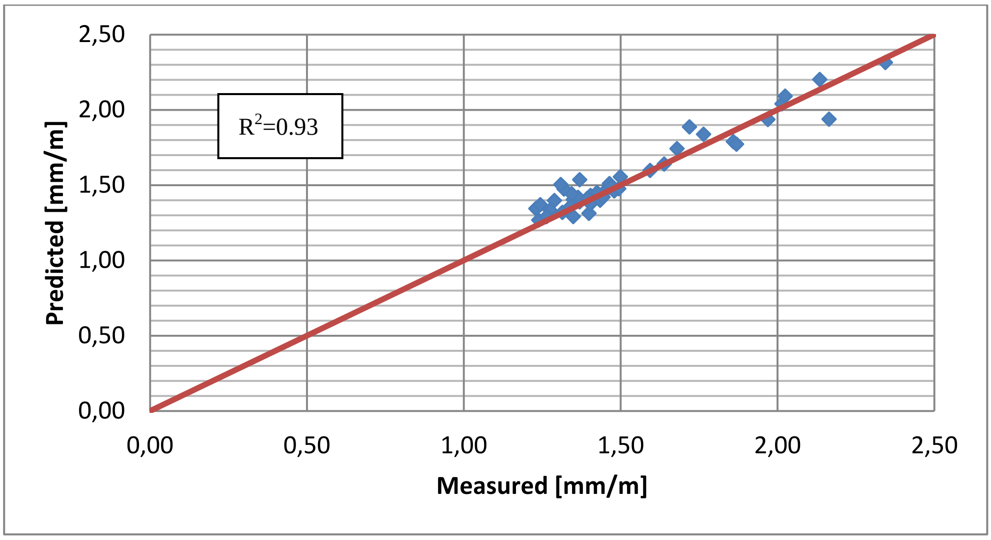

Figure 9-22. Correlation between measured and predicted IRI, Trädet (RV46), Sweden.

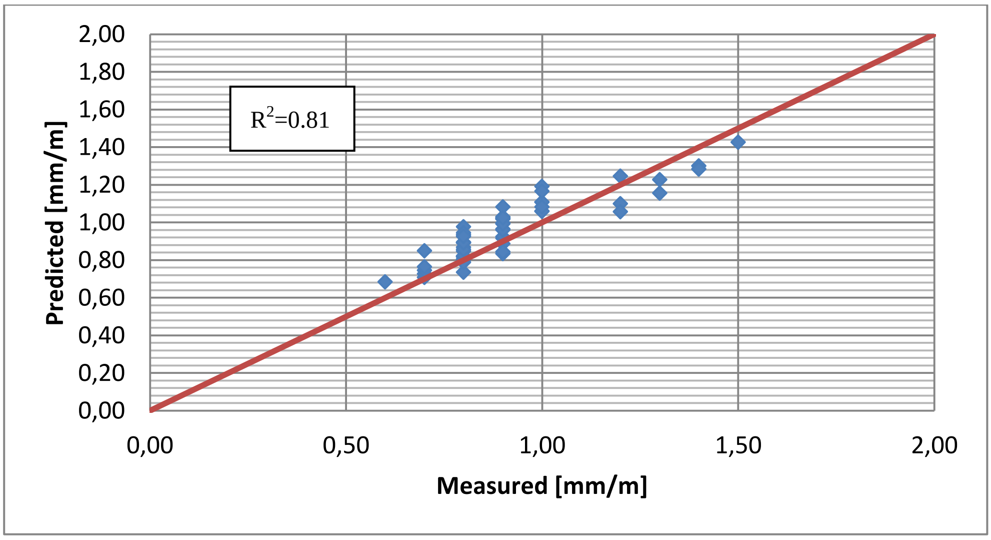

Figure 9-23. Correlation between measured and predicted IRI, Fastarp (E6), Sweden.

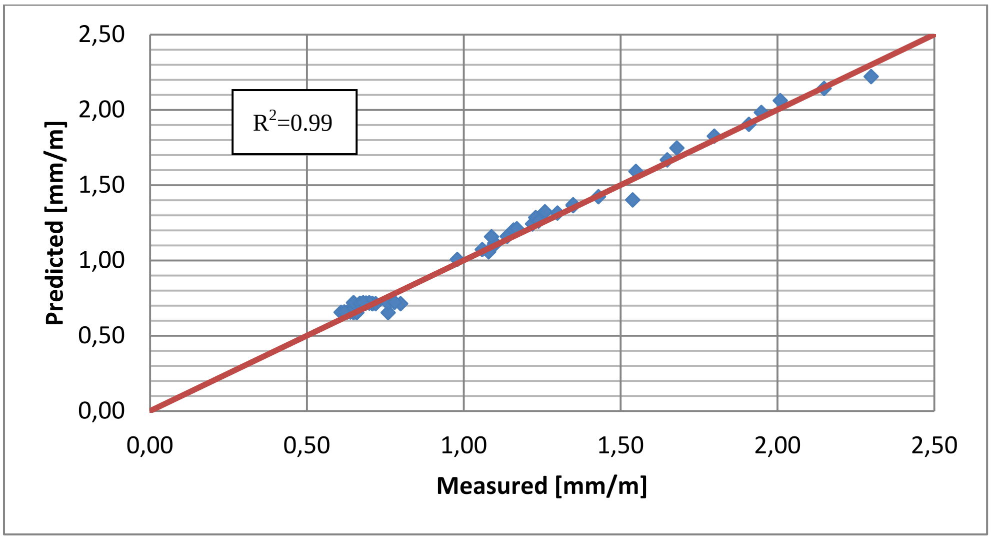

Figure 9-24. Correlation between measured and predicted IRI, Tvååker (E6), Sweden.

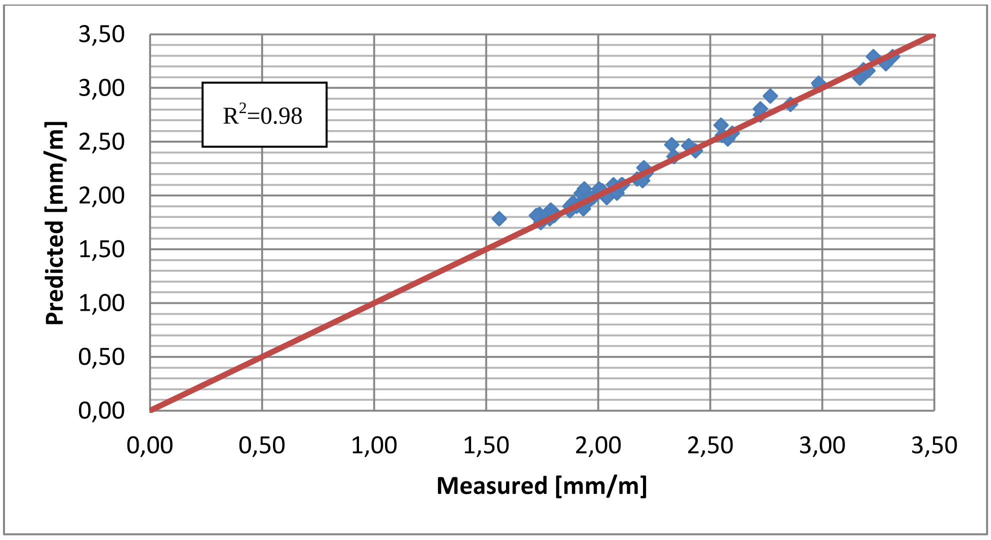

Figure 9-25. Correlation between measured and predicted IRI, Borlänge (RV60), Sweden.

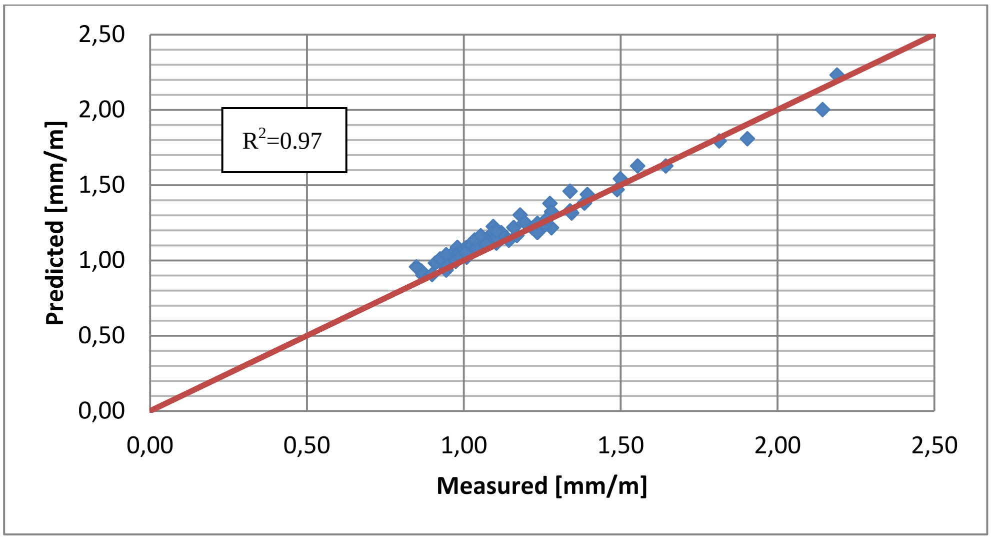

Figure 9-26. Correlation between measured and predicted IRI, Äppelbo (RV71), Sweden.

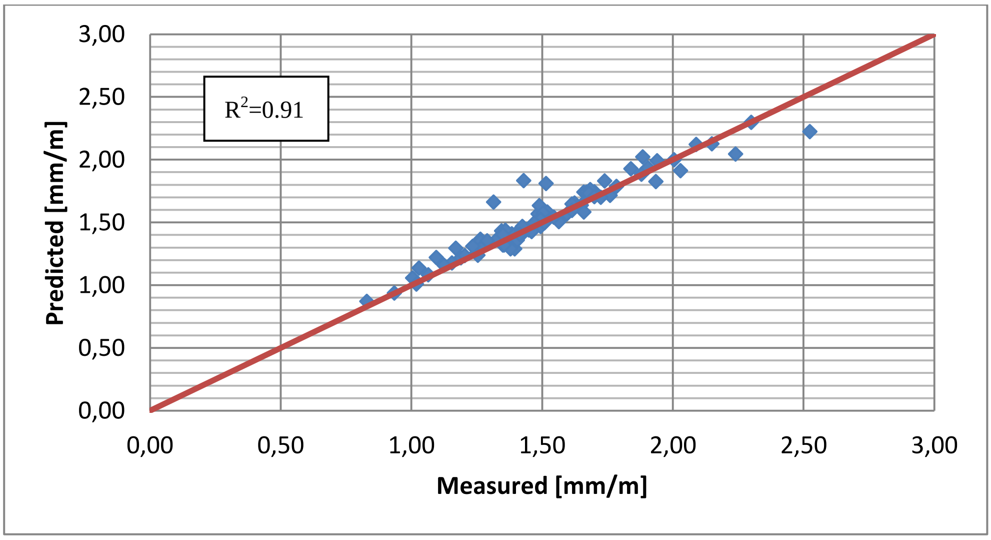

Figure 9-27. Correlation between measured and predicted IRI, Bjursås (RV80), Sweden.

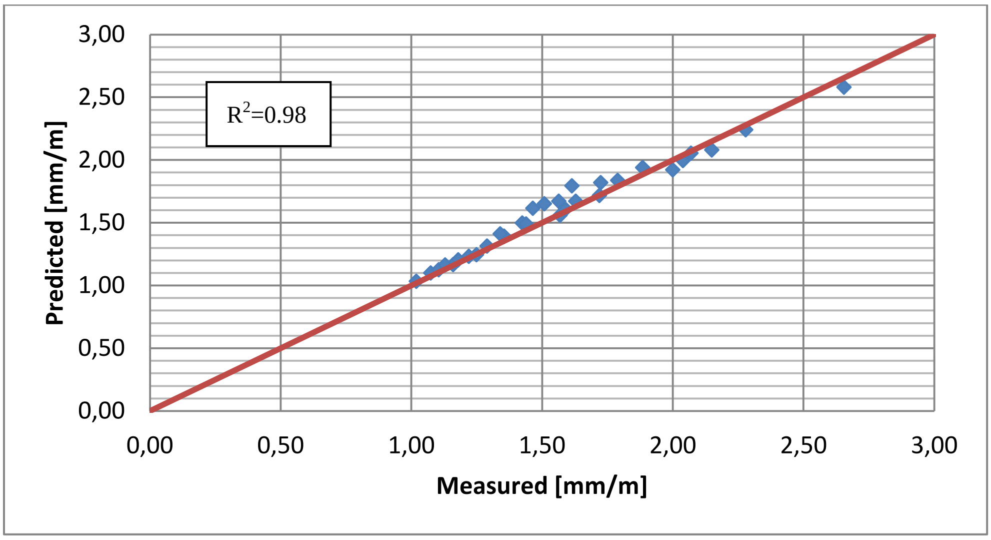

Figure 9-28. *Correlation between measured and predicted IRI, Sollefteå (RV90), Sweden.*

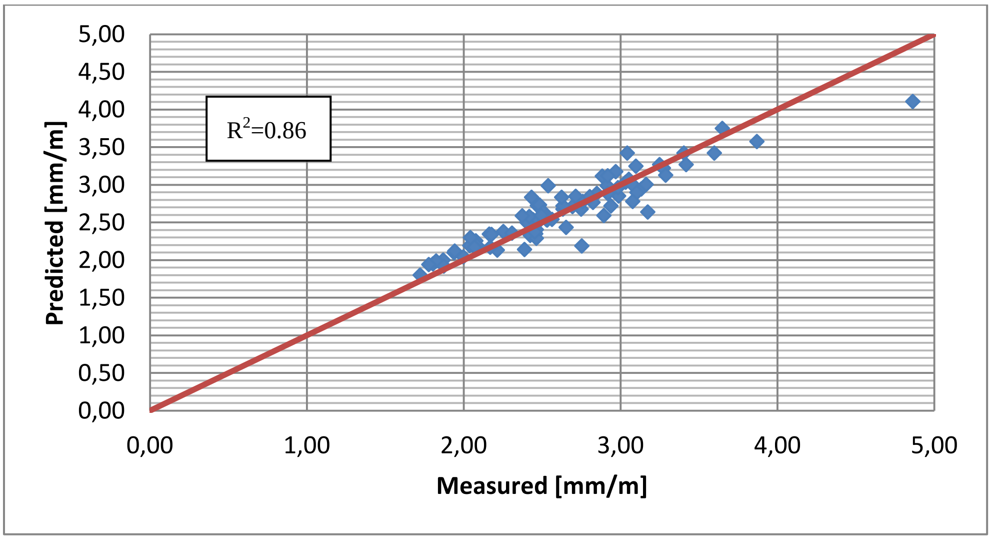

Figure 9-29. *Correlation between measured and predicted IRI, Kaxås (Road 675), Sweden.*

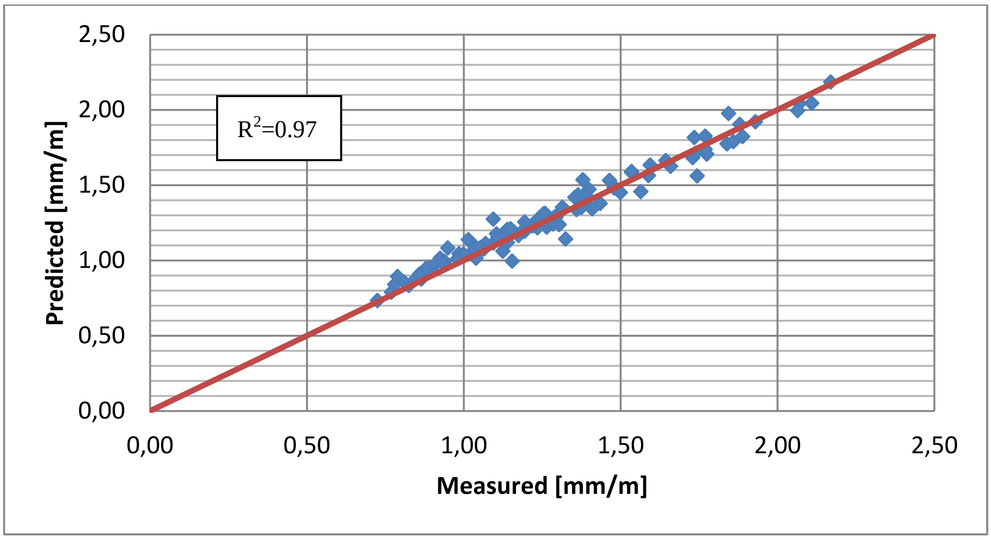

Figure 9-30. Correlation between measured and predicted IRI, Kvicksund (RV35), Sweden.

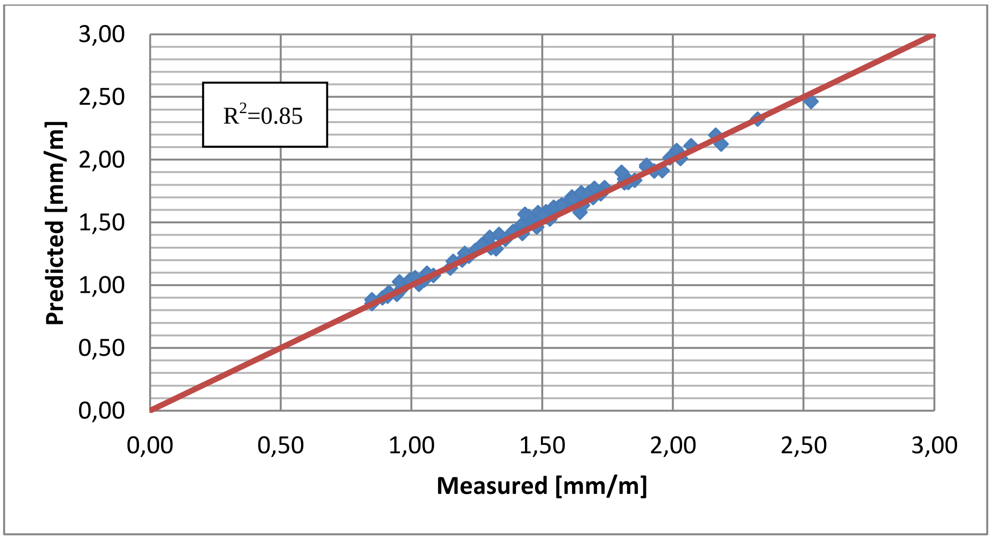

Figure 9-31. Correlation between measured and predicted IRI, Häggenås (RV45), Sweden.

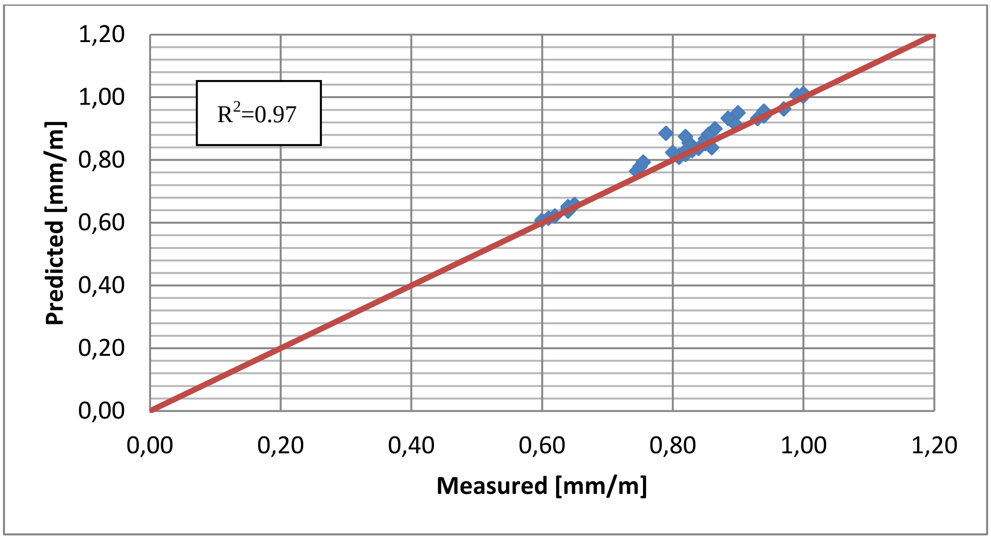

Figure 9-32. Correlation between measured and predicted IRI (All Danish sections).

In the table below the degree of correlation (R^2-value) for the roughness is summarised for Figure 9-19 to Figure 9-32:

Table 9-21. Degree of correlation between measured and predicted roughness.

Section	R^2-value for roughness
All Norwegian	0.87
Nässjö (RV31)	0.82
Målilla (RV34)	0.89
Trädet (RV46)	0.93
Fastarp (E6)	0.81
Tvååker (E6)	0.99
Borlänge (RV60	0.98
Äppelbo (RV71)	0.97
Bjursås (RV80)	0.91
Sollefteå (RV90)	0.98
Kaxås (Road 675)	0.86
Kvicksund (RV35)	0.97
Häggenås (RV45)	0.85
All Danish	0.97

It can be seen from the table above that there is a good correlation (R^2-value close to '1') between the measured and the predicted roughness on the calibrated sections.

The used section specific calibration factors are included in Table 9-22 at the end of this appendix.

E.4 Values for section specific calibration factors

The table below summarizes the section specific calibration factors for each subsection of the sections calibrated for Nordic conditions in this project. Additionally the table shows the number of uniform subsections for each section. These numbers are used for evaluation and weighting of the calibration factors for Nordic conditions.

Table 9-22. Section specific calibration factors for each subsection of each section calibrated in this project.

Section	**Subsection**	**Number of uniform subsections**	**Calibrated values for each subsection**							
			K_{cia}	K_{rid}	K_{pp}	K_{rst}	K_{gm}	K_{gs}	K_{gc}	K_{gr}
			Norwegian sections							
RV5	-	1	0.76[1)]	0.00	0.00	2.30	1.40	1.00	0.00	1.00
E39	-	1	0.76[1)]	0.20	0.00	4.50	2.10	1.00	1.00	0.50
E6	-	1	0.45[2)]	0.00	0.00	17.00	0.00	1.00	3.00	0.70
E8	-	1	0.76[1)]	0.00	0.00	15.00	0.70	1.00	0.00	0.00
			Swedish sections							
Nässjö-RV31	1	2	0.87[3)]	0.00	1.00	5.80	0.00	1.00	1.00	0.40
	2	2	1.24[3)]	0.00	0.00	6.30	0.10	1.00	1.00	0.50
	3	5	0.90[3)]	0.30	0.00	5.70	0.00	1.00	1.00	0.45
	4	2	0.70[3)]	0.30	0.00	7.20	2.70	1.00	1.00	0.50
Målilla-RV34	1	4	0.65[3)]	0.00	0.00	3.20	1.10	1.00	0.00	0.80
	2	3	0.85[3)]	0.00	0.00	3.00	1.00	1.00	0.00	1.00
	3	2	0.60[3)]	0.00	0.00	3.00	0.00	1.00	5.00	0.00
	4	1	0.65[3)]	0.00	0.00	3.50	1.00	1.00	3.00	1.00
Trädet-RV46	1	3	0.90[3)]	0.30	0.00	1.50	0.30	1.00	0.00	0.20
	2	2	0.98[3)]	0.20	0.00	2.00	0.30	1.00	0.00	1.00
	3	2	0.76[3)]	0.30	0.00	2.00	0.70	1.00	0.00	1.00
	4	1	0.85[3)]	0.30	0.00	2.30	0.50	1.00	0.80	0.40
	5	1	0.80[3)]	0.00	1.00	3.80	0.50	1.00	0.80	0.40

Section	Subsection	Number of uniform subsections	Calibrated values for each subsection							
			K_{cia}	K_{rid}	K_{pp}	K_{rst}	K_{gm}	K_{gs}	K_{gc}	K_{gr}
Fastarp-E6	1	1	0.99[3)]	0.00	0.00	7.00	0.30	1.00	0.20	0.30
	2	1	0.99[3)]	0.00	0.00	7.00	0.70	1.00	0.40	0.80
	3	1	0.99[3)]	0.00	0.00	5.30	0.80	1.00	1.50	1.00
	4	1	0.99[3)]	0.00	0.00	4.00	0.20	1.00	1.00	2.00
	5	1	0.99[3)]	0.30	0.00	5.00	1.50	1.00	1.00	0.50
	6	1	0.99[3)]	0.70	0.00	4.90	1.40	1.00	0.00	1.00
	7	1	0.99[3)]	0.20	0.00	9.30	0.50	1.00	1.00	0.50
Tvååker-E6	1	1	0.81[3)]	0.00	0.00	3.70	0.00	1.00	0.00	0.00
	2	3	0.86[3)]	0.00	0.00	4.00	0.00	1.00	0.00	0.00
	3	1	0.91[3)]	0.00	0.00	5.50	0.00	1.00	0.00	0.00
	4	1	1.18[3)]	0.00	0.00	7.00	0.60	1.00	0.00	1.00
	5	3	1.10[3)]	0.00	0.00	6.50	0.20	1.00	0.50	1.00
	6	1	1.06[3)]	0.00	0.00	4.70	0.60	1.00	0.00	1.00
Borlänge-RV60	1	1	0.50[3)]	0.00	0.00	8.50	0.30	1.00	0.00	1.00
	2	1	0.43[3)]	0.00	0.00	10.00	0.00	1.00	0.00	1.00
	3	1	0.51[3)]	0.00	0.00	7.50	0.40	1.00	0.00	1.00
	4	1	0.50[3)]	0.00	0.00	7.00	0.20	1.00	0.00	1.00
	5	1	0.48[3)]	0.00	0.00	8.30	0.40	1.00	0.00	1.00
	6	1	0.32[3)]	0.00	0.00	9.00	0.10	1.00	0.00	1.00
	7	1	0.46[3)]	0.00	0.00	9.50	0.20	1.00	0.00	1.00
	8	1	0.42[3)]	0.00	0.00	9.00	0.80	1.00	0.00	1.00
	9	1	0.48[3)]	0.00	0.00	8.50	0.10	1.00	0.00	1.00
	10	1	0.55[3)]	0.00	0.00	8.00	1.00	1.00	0.00	1.00

Section	Subsection	Number of uniform subsections	Calibrated values for each subsection							
			K_{cia}	K_{rid}	K_{pp}	K_{rst}	K_{gm}	K_{gs}	K_{gc}	K_{gr}
Äppelbo-RV71	1	1	1.20[3)]	0.30	0.00	4.50	1.40	1.00	0.50	1.00
	2	1	1.30[3)]	0.30	0.50	4.00	1.30	1.00	0.00	1.00
	3	1	1.44[3)]	0.30	0.00	4.20	0.30	1.00	1.00	0.80
	4	1	1.64[3)]	0.00	0.00	4.20	0.55	1.00	0.60	0.60
	5	1	1.67[3)]	0.00	0.00	3.80	0.30	1.00	0.00	0.30
	6	1	1.64[3)]	0.00	0.50	4.00	0.20	0.80	0.00	1.00
	7	1	1.41[3)]	0.30	0.50	3.10	0.30	1.00	0.00	1.00
Bjursås-RV80	1	1	0.38[3)]	0.30	0.00	5.00	1.20	1.00	0.00	1.00
	2	1	0.33[3)]	0.50	0.00	5.50	1.10	1.00	0.00	1.00
	3	1	0.38[3)]	0.30	0.00	5.00	0.10	1.00	2.00	0.50
	4	1	0.36[3)]	0.50	0.00	4.30	1.50	1.00	1.00	1.00
	5	1	0.55[3)]	0.00	0.00	4.30	0.20	1.00	1.00	1.00
	6	1	0.46[3)]	0.00	0.00	6.50	0.80	1.00	1.00	1.00
	7	1	0.49[3)]	0.00	0.00	6.50	0.80	1.00	1.00	1.00
	8	1	0.50[3)]	0.00	0.00	6.00	0.60	1.00	1.00	1.00
	9	1	0.67[3)]	0.00	0.00	5.50	1.70	1.00	1.00	1.00
	10	1	0.50[3)]	0.00	0.00	5.20	1.60	1.00	1.00	1.00
Sollefteå-RV90	1	1	0.79[3)]	0.00	0.00	4.40	0.40	1.00	0.00	1.00
	2	1	0.26[3)]	0.00	0.00	3.70	0.80	1.00	0.00	1.00
	3	1	0.66[3)]	0.00	0.00	1.00	0.40	1.00	0.00	1.00
	4	1	0.47[3)]	0.00	0.00	2.80	0.60	1.00	0.00	1.00
	5	1	0.39[3)]	0.00	0.00	3.80	0.70	1.00	0.00	1.00
	6	1	0.28[3)]	0.00	0.00	4.50	1.70	1.00	0.00	1.00
	7	1	0.31[3)]	0.00	0.00	4.30	1.10	1.00	0.00	1.00
	8	1	0.28[3)]	0.00	0.00	4.00	2.10	1.00	0.00	1.00

Section	Subsection	Number of uniform subsections	Calibrated values for each subsection							
			K_{cia}	K_{rid}	K_{pp}	K_{rst}	K_{gm}	K_{gs}	K_{gc}	K_{gr}
Kaxås-Road 675	1	1	0.76[3)]	0.00	0.00	5.00	2.80	1.00	0.00	1.00
	2	1	0.76[3)]	0.00	0.00	4.00	2.30	1.00	0.00	1.00
	3	1	0.76[3)]	0.00	0.00	6.50	1.75	1.00	0.00	1.00
	4	1	0.76[3)]	0.00	0.00	4.50	1.85	1.00	0.00	1.00
	5	1	0.76[3)]	0.00	0.00	3.50	2.70	1.00	0.00	1.00
	6	1	0.76[3)]	0.00	0.00	3.00	2.70	1.00	0.00	1.00
	7	1	0.76[3)]	0.00	0.00	3.00	3.00	1.00	0.00	1.00
	8	1	0.76[3)]	0.00	0.00	4.00	3.00	1.00	0.00	1.00
	9	1	0.76[3)]	0.00	0.00	2.70	2.50	1.00	0.00	1.00
	10	1	0.76[3)]	0.00	0.00	7.00	1.50	1.00	0.00	1.00
	11	1	0.76[3)]	0.00	0.00	3.50	3.00	1.00	0.00	1.00
	12	1	0.76[3)]	0.00	0.00	3.50	3.00	1.00	0.00	1.00
Kvicksund-RV35	1	1	0.30[3)]	0.00	0.00	7.50	1.80	1.00	0.00	1.00
	2	1	0.27[3)]	0.00	0.00	8.90	0.60	1.00	0.00	1.00
	3	1	0.45[3)]	0.00	0.00	8.90	1.90	1.00	0.00	1.00
	4	1	0.30[3)]	0.00	0.00	8.00	0.20	1.00	0.70	1.00
	5	1	0.47[3)]	0.00	0.00	8.00	0.10	1.00	1.00	1.00
	6	1	0.30[3)]	0.00	0.00	7.30	1.90	1.00	0.00	1.00
	7	1	0.30[3)]	0.00	0.00	7.30	1.00	1.00	1.50	1.00
	8	1	0.31[3)]	0.00	0.00	7.90	0.40	1.00	1.50	1.00
	9	1	0.35[3)]	0.00	0.00	8.50	0.20	1.00	1.50	1.00
	10	1	0.33[3)]	0.00	0.00	8.50	0.80	1.00	1.50	1.00
	11	1	0.27[3)]	0.00	0.00	8.50	0.20	1.00	1.50	1.00

Section	Subsection	Number of uniform subsections	Calibrated values for each subsection							
			K_{cia}	K_{rid}	K_{pp}	K_{rst}	K_{gm}	K_{gs}	K_{gc}	K_{gr}
Häggenås-RV45	1	1	0.51 3)	0.30	0.00	1.70	0.40	1.00	0.00	1.00
	2	1	0.28 3)	0.30	0.00	1.90	0.50	1.00	0.00	1.00
	3	1	0.16 3)	0.30	0.00	1.90	0.00	1.00	0.00	1.00
	4	1	0.16 3)	0.30	0.00	2.40	0.20	1.00	0.00	1.00
	5	1	0.16 3)	0.30	0.00	2.10	0.10	1.00	0.00	1.00
	6	1	0.45 3)	0.00	0.00	2.10	0.10	1.00	0.00	1.00
	7	1	0.49 3)	0.20	0.00	1.60	0.80	1.00	0.00	1.00
	8	1	0.96 3)	0.15	0.00	1.20	0.70	1.00	0.00	1.00
	9	1	0.93 3)	0.15	0.00	1.75	0.20	1.00	0.40	1.00
	10	1	0.46 3)	0.20	0.00	1.80	0.30	1.00	0.00	1.00
			Danish sections							
M90-1	-	1	0.76 1)	0.00	0.00	0.60	0.00	1.00	0.00	0.00
M90-2	-	1	0.76 1)	0.00	0.00	2.50	0.00	1.00	0.20	0.00
M64-1	-	2	0.76 1)	0.00	0.00	8.00	0.00	1.00	0.00	0.07
M64-2	-	2	0.76 1)	0.00	0.00	11.00	0.00	1.00	0.00	0.15
Road 344	-	1	0.76 1)	0.00	0.00	2.00	0.60	1.00	0.00	0.00

1) Weighted average of K_{cia} for Swedish test sections.

2) Value that result in best fit for this specific test section.

3) Values from Table 9-19.

Appendix F Evaluation of grouping of test sections

As described in Chapter 5.2 it is envisioned that the input parameters listed below could have great influence on the deterioration of the pavement structure:

› Heavy traffic: - Average Annual Daily Traffic for heavy traffic ($AADT_{heavy}$) or Equivalent Standard Axle Loads (ESALs)

› Bearing capacity: - Structural Number (SNP)

- Subgrade strength

› Climate: - Mean Monthly Precipitation (MMP)

The $AADT_{heavy}$, ESAL and MMP are given from the historical data, whereas SNP and subgrade strength can be calculated from the historical data using the equations below from HDM-4:

The SNP values can be determined based on e.g. Falling Weight Deflectometer (FWD) measurements as:

$$SNP = 3.2 \times \left(\frac{d_0}{1{,}000}\right)^{-0.63}$$

where: - 'd_0' is the centre deflection in microns.

The strength of the subgrade can be determined based on e.g. FWD measurements as.

$$E_{Subgrade} = \frac{52{,}000}{d_{900}^{1.5}}$$

where: - 'd_{900}' is the deflection in microns at a distance of 900 mm from the centre deflection.

The two tables below show the results, which have formed the basis for the grouping of the test sections:

Table 9-23. Overview of input parameters used in evaluation.

Section	$AADT_{heavy}$ 1) **[-]**	**SNP 2) [-]**	**MMP 3) [mm]**	**Strength of subgrade 2) [MPa]**
	Swedish sections			
E6 (F)	2,042	8.72	62	55
E6 (T)	2,043	8.88	69	61
RV31	350	7.05	60	104
RV34	293	5.42	50	40
RV46	164	6.23	61	82
RV60	459	8.43	50	98
RV71	139	5.93	53	51
RV80	222	6.31	50	83
RV90	115	5.73	47	53
Road 675	22	3.90	57	62
RV35	445	7.94	44	202
RV45	134	5.81	60	131
	Norwegian sections			
RV5	92	5.42	177	100
E39	895	5.85	105	200
E6	92	9.69	71	30
E8	229	5.63	83	50

Section	$AADT_{heavy}$ [1)] **[-]**	**SNP[2)] [-]**	**MMP[3)] [mm]**	**Strength of subgrade[2)] [MPa]**
	Danish sections			
M90-1	3,391	6.67	64	40[4)]
M90-2	3,391	7.57	64	40[4)]
M64-1	1,921	7.20	65	100[5)]
M64-2	1,921	8.91	65	100[5)]
Road 344	936	8.91	65	172

[1)] From relevant tables in Appendix C.
[2)] Weighted average values for all subsections, if any.
[3)] From relevant tables in Appendix A.
[4)] Assumed values where 'd_0' was not given in the historical data, but a range of 40-70 MPa was estimated; the low value was used.
[5)] Assumed values where 'd_0' was not given in the historical data, but a range of 100-150 MPa was estimated; the low value was used

In Appendix D the standard calibration factors were listed, see Table 9-16, with the default value in the HDM-4 program. In Appendix E the section specific calibration factors were calibrated based on the historical data and reported in Table 9-22 at the end of the same appendix.

Each section used in the calibration process consists of one or more subsections; in the table below the calibration factors are given for each test section (weighted average of subsections where applicable) based on Table 9-16 and Table 9-22:

Table 9-24. Section specific calibration factors for each test section based on values in Table 9-16 and Table 9-22 (weighted average of subsections, where applicable).

Calibration factor[1)]	Norway				Sweden												Denmark				
	RV5	E39	E6	E8	RV31-Nässjö	RV34-Målilla	RV46-Trädet	E6-Tvååker	E6-Fastarp	RV90-Sollefteå	Road 675-Kaxås	RV60-Borlänge	RV71-Äppelbo	RV80-Bjursås	RV35-Kvicksund	RV45-Häggenås	M90-1	M90-2	M64-1	M64-2	Road 344
K_{cia}	0.76	0.76	0.45	0.76	0.92	0.70	0.87	0.98	0.99	0.43	0.76	0.47	1.47	0.46	0.33	0.46	0.77	0.77	0.77	0.77	0.77
K_{pp}	0.00	0.00	0.00	0.00	0.18	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K_{rid}	0.00	0.20	0.00	0.00	0.19	0.00	0.24	0.00	0.17	0.00	0.00	0.00	0.17	0.16	0.00	0.22	0.00	0.00	0.00	0.00	0.00
K_{rst}	2.30	4.50	17.0	15.0	6.10	3.13	2.07	5.24	6.07	3.56	4.18	8.53	3.97	5.38	8.12	1.85	0.60	2.50	8.00	11.0	2.00
K_{gm}	1.40	2.10	0.00	0.70	0.51	0.84	0.43	0.18	0.77	0.98	2.51	0.35	0.62	0.96	0.83	0.33	0.00	0.00	0.00	0.00	0.60
K_{gs}	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
K_{gc}	0.00	1.00	3.00	0.00	0.18	1.30	0.18	0.15	0.73	0.00	0.00	0.00	0.30	0.20	0.84	0.04	0.00	0.20	0.00	0.00	0.00
K_{gr}	1.00	0.50	0.70	0.00	0.46	0.72	0.60	0.50	0.87	1.00	1.00	1.00	0.81	0.95	1.00	1.00	0.00	0.00	0.07	0.15	0.00

[1)] Values for standard calibration factors can be seen in Appendix D.

Based on the calibration factors in the table above the influence of heavy traffic ($AADT_{heavy}$), Structural Number (SNP), subgrade strength and Mean Monthly Precipitation (MMP) is evaluated. In the figures below the most essential section specific calibration factors (K_{cia}, K_{rst}, K_{gm}, K_{gc} and K_{gr}) are shown in relation to the various input parameters:

F.1 Heavy traffic ($AADT_{heavy}$)

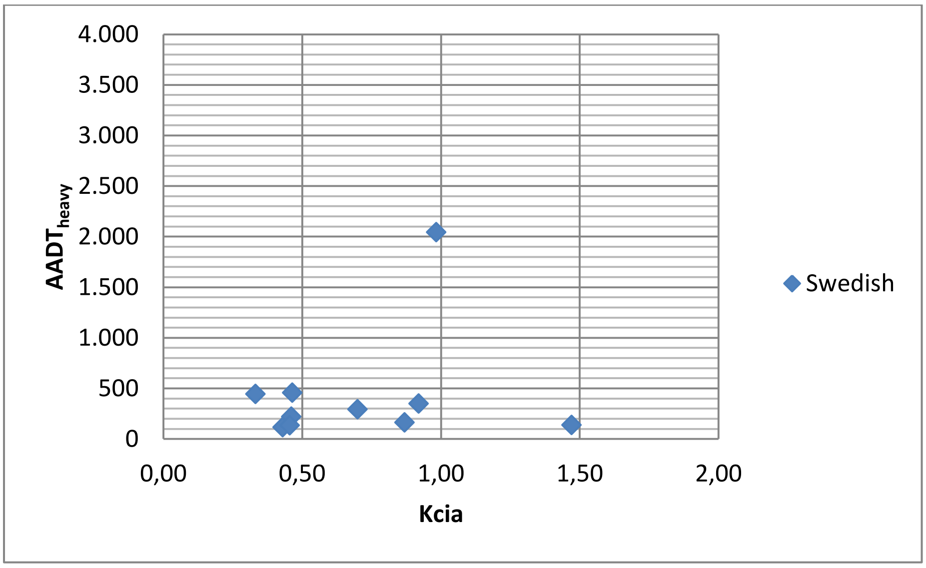

Figure 9-33. Calibration factor K_{cia} vs. $AADT_{heavy}$ (only Sweden has data to determine K_{cia}).

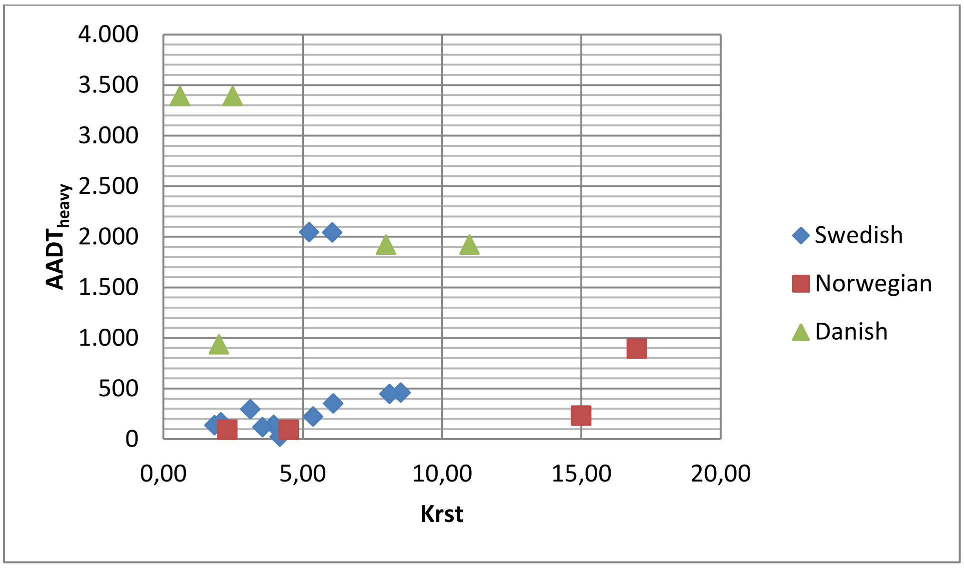

Figure 9-34. Calibration factor K_{rst} vs. $AADT_{heavy}$.

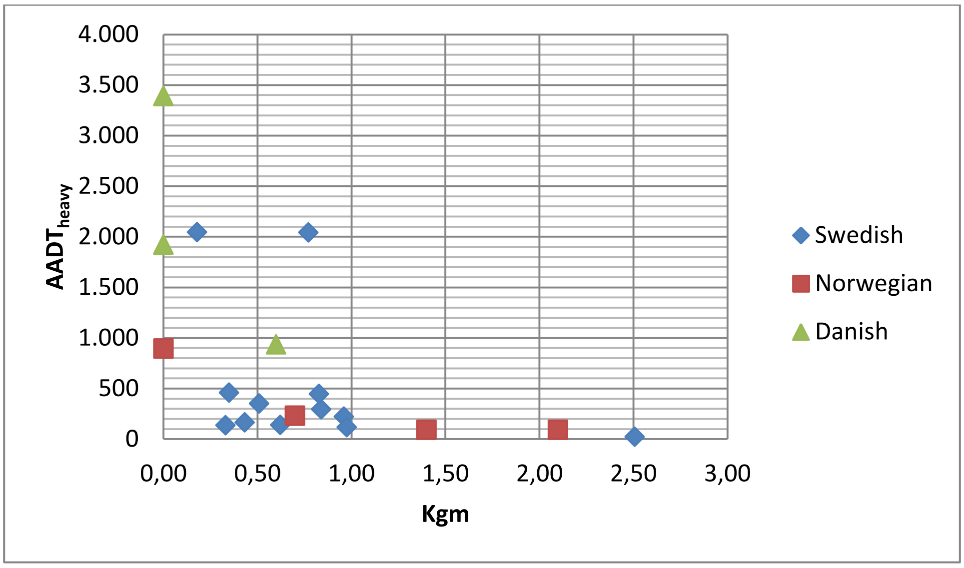

Figure 9-35. Calibration factor K_{gm} vs. $AADT_{heavy}$.

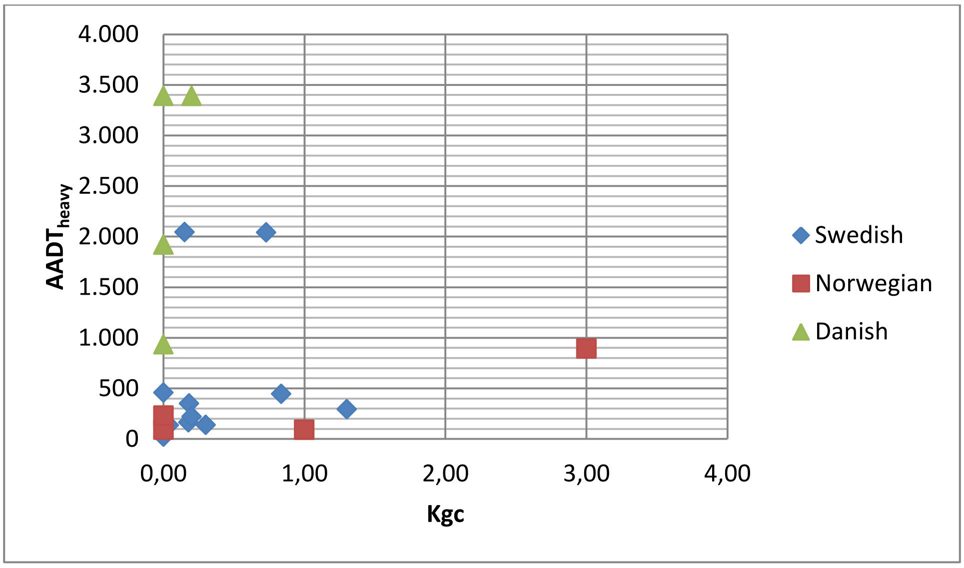

Figure 9-36. Calibration factor K_{gc} vs. $AADT_{heavy}$

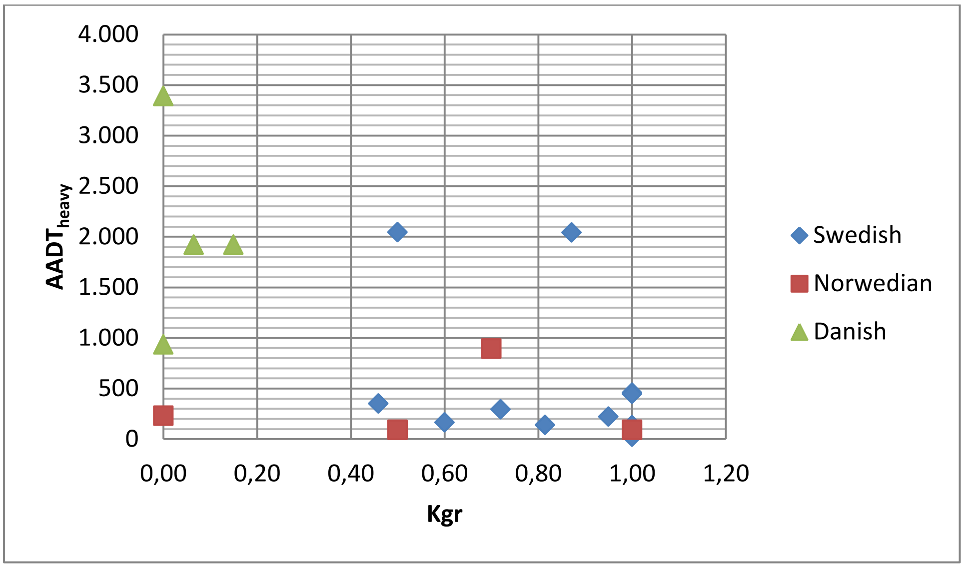

Figure 9-37. Calibration factor K_{gr} vs. $AADT_{heavy}$

F.2 Structural Number (SNP)

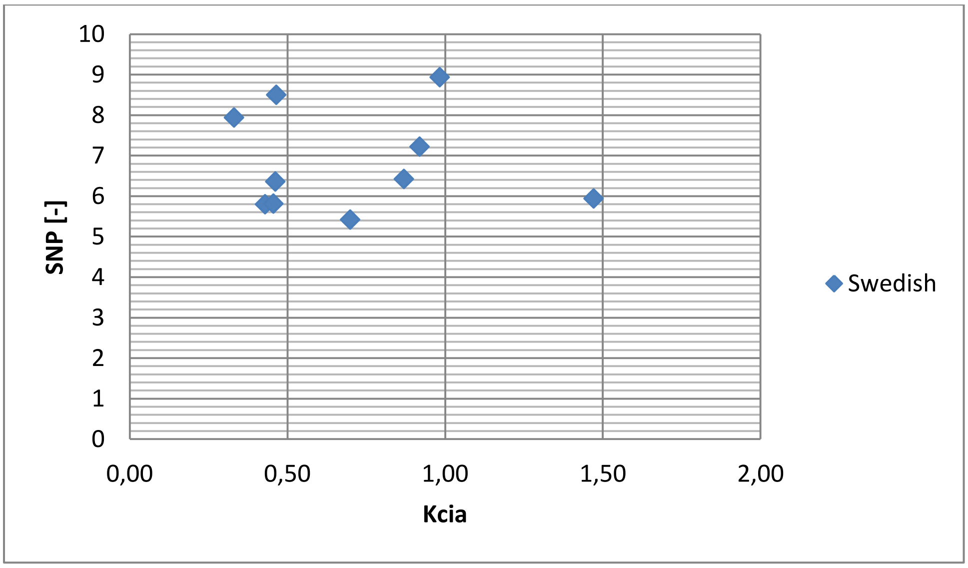

Figure 9-38. Calibration factor K_{cia} vs. SNP (only Sweden has data to determine K_{cia}).

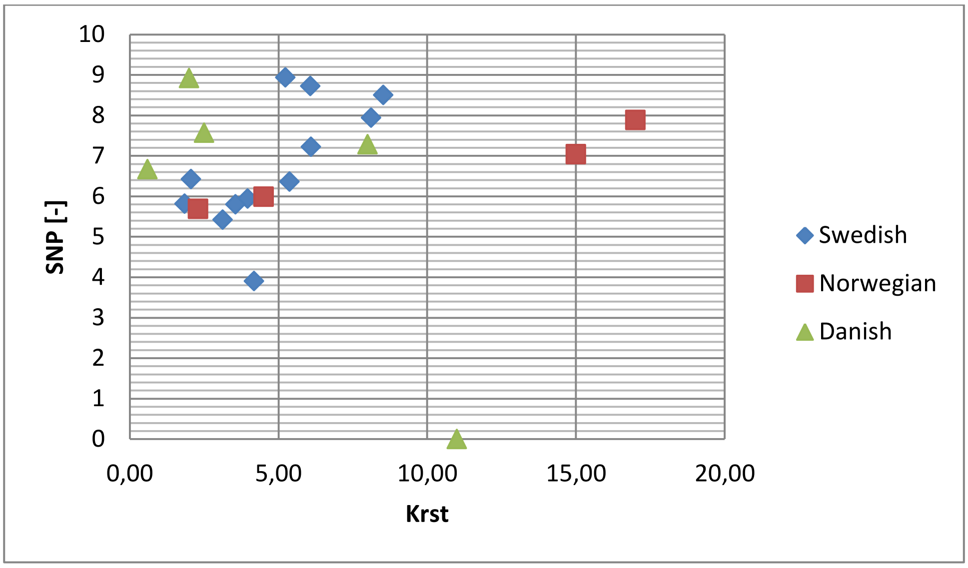

Figure 9-39. *Calibration factor K_{rst} vs. SNP.*

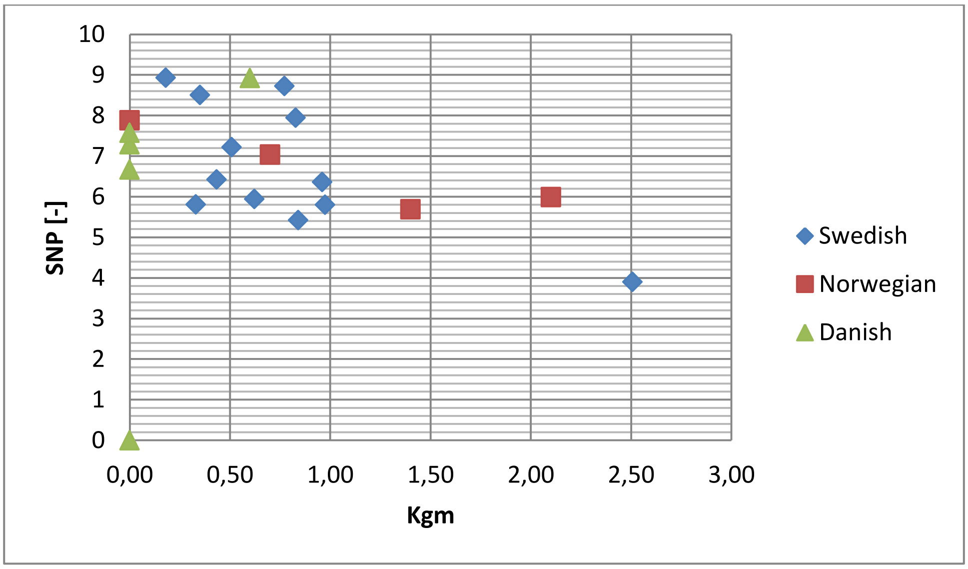

Figure 9-40. *Calibration factor K_{gm} vs. SNP.*

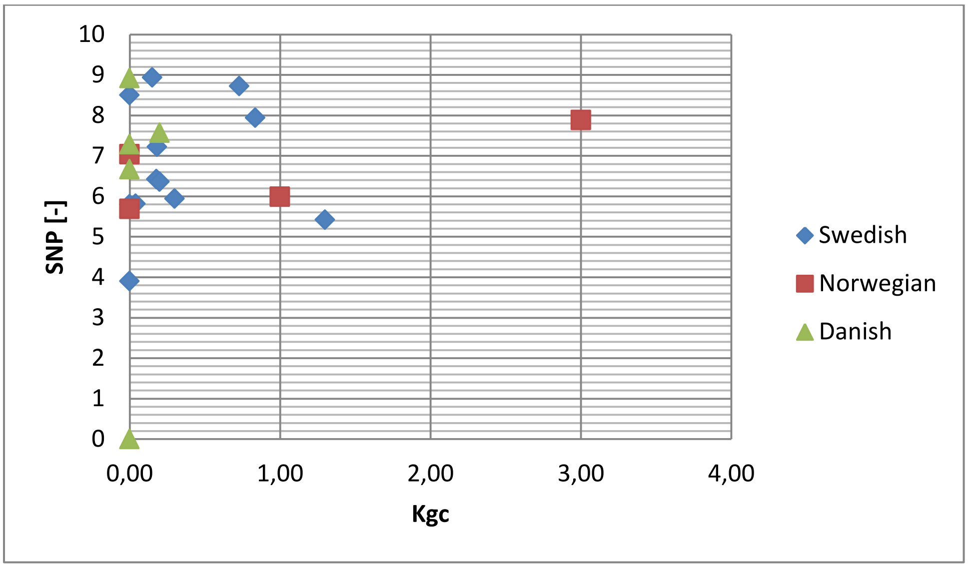

Figure 9-41. Calibration factor K_{gc} vs. SNP

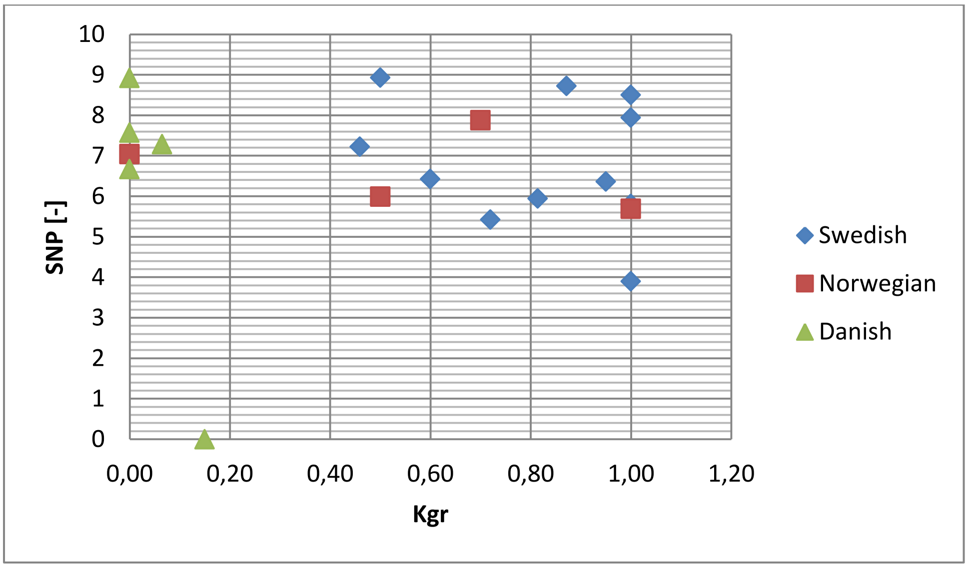

Figure 9-42. Calibration factor K_{gr} vs. SNP

F.3 Subgrade strength

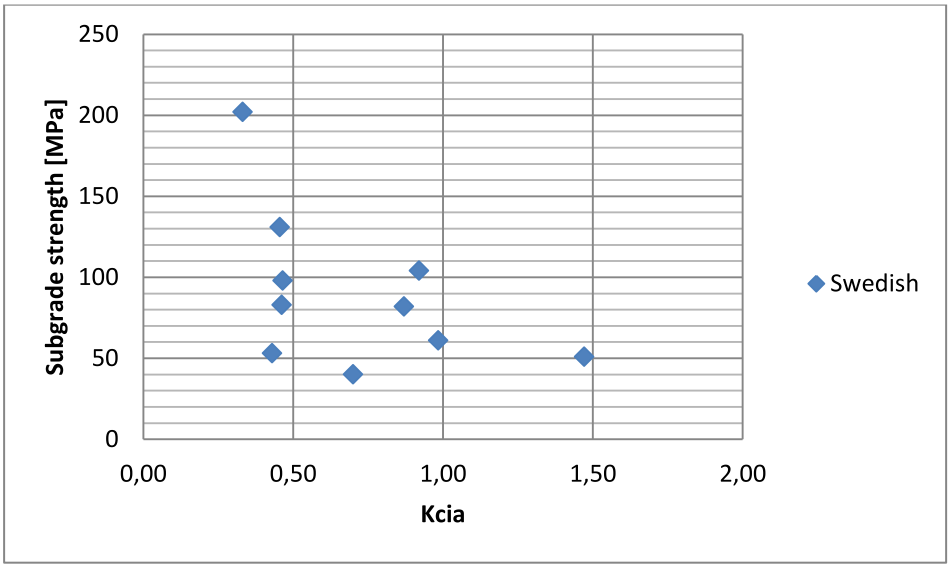

Figure 9-43. Calibration factor K_{cia} vs. subgrade strength (only Sweden has data to determine K_{cia}).

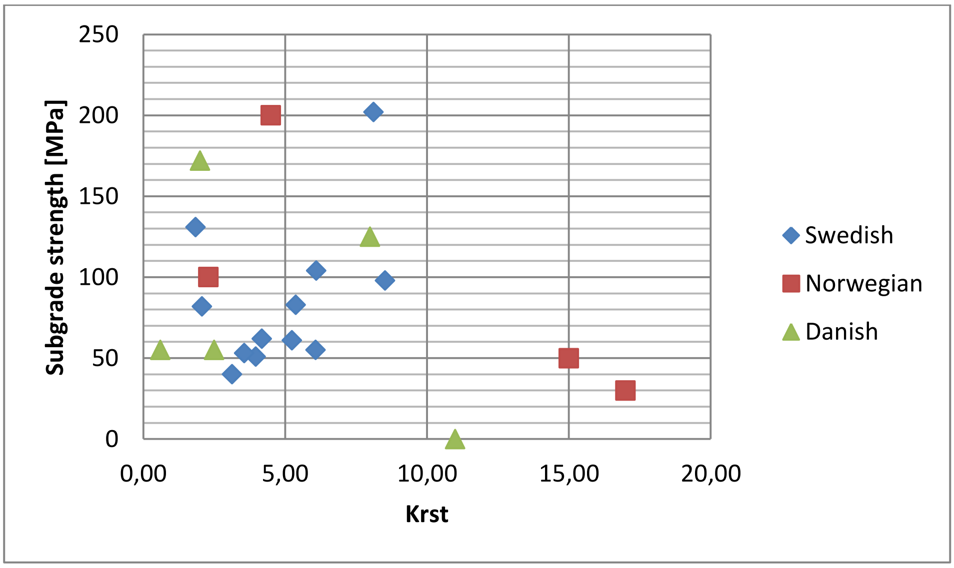

Figure 9-44. Calibration factor K_{rst} vs. subgrade strength.

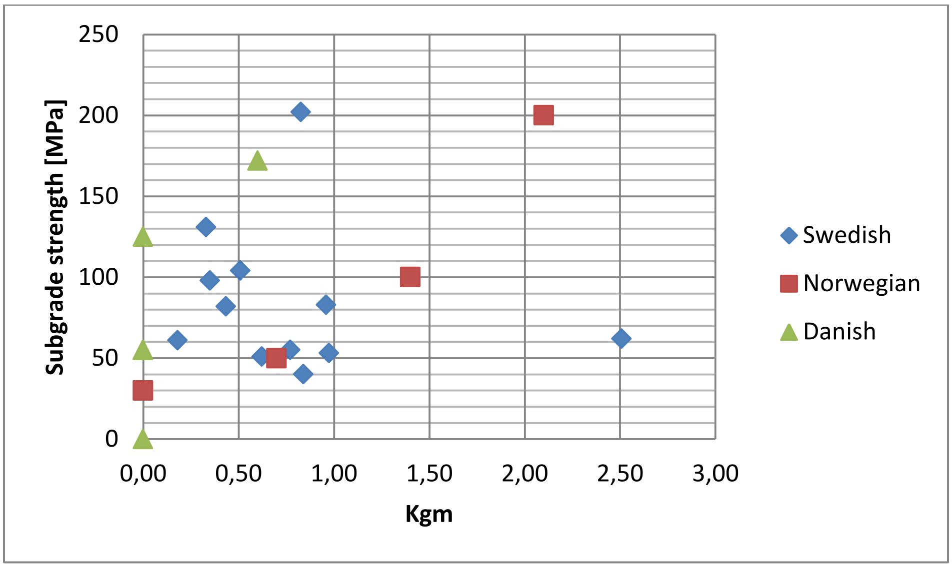

Figure 9-45. Calibration factor K_{gm} vs. subgrade strength.

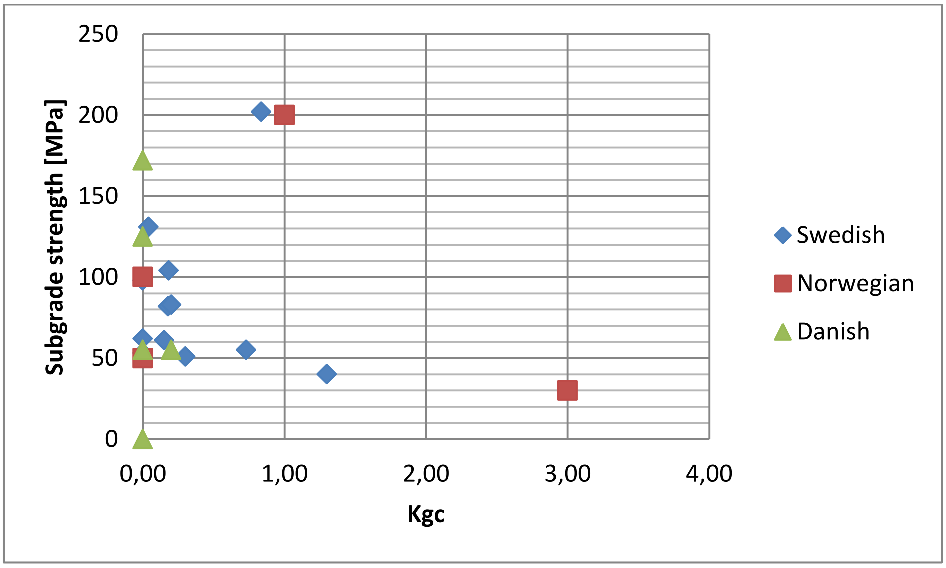

Figure 9-46. Calibration factor K_{gc} vs. subgrade strength.

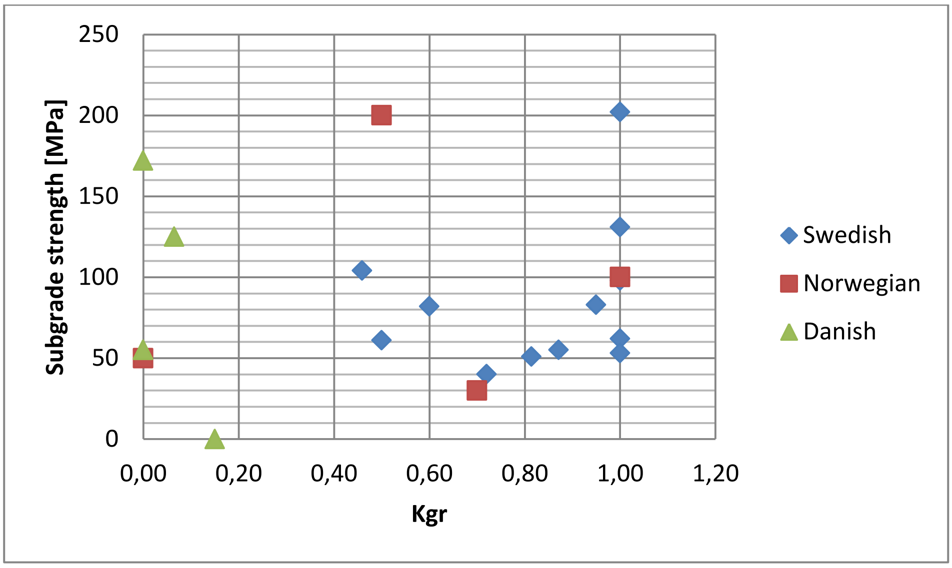

Figure 9-47. *Calibration factor K_{gr} vs. subgrade strength.*

F.4 Mean Monthly Precipitation (MMP)

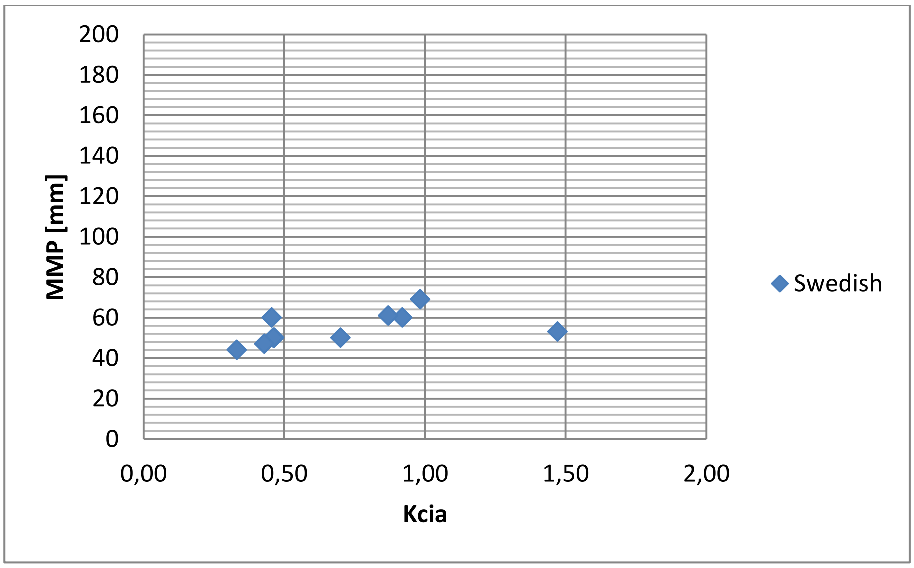

Figure 9-48. *Calibration factor Kcia vs. MMP (only Sweden has data to determine Kcia).*

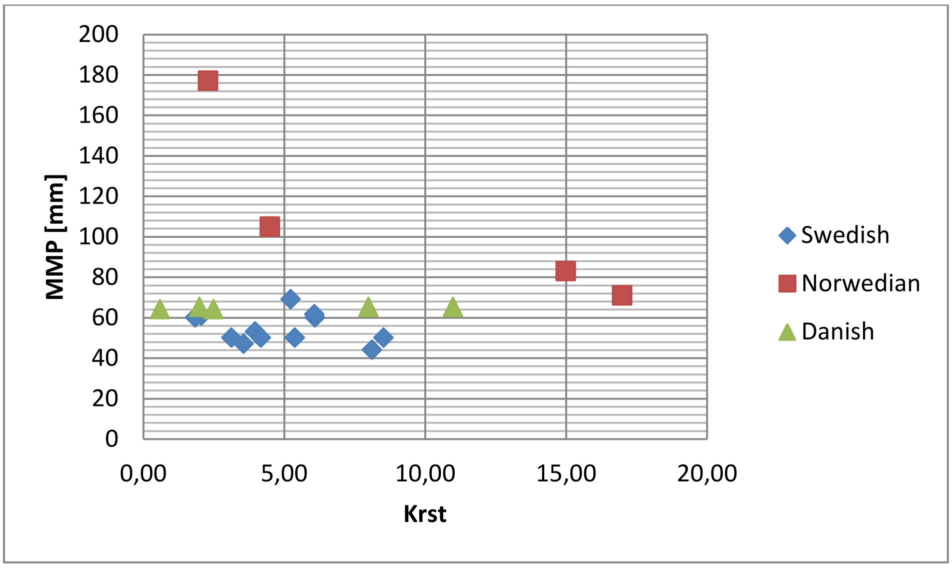

Figure 9-49. Calibration factor K_{rst} vs. MMP.

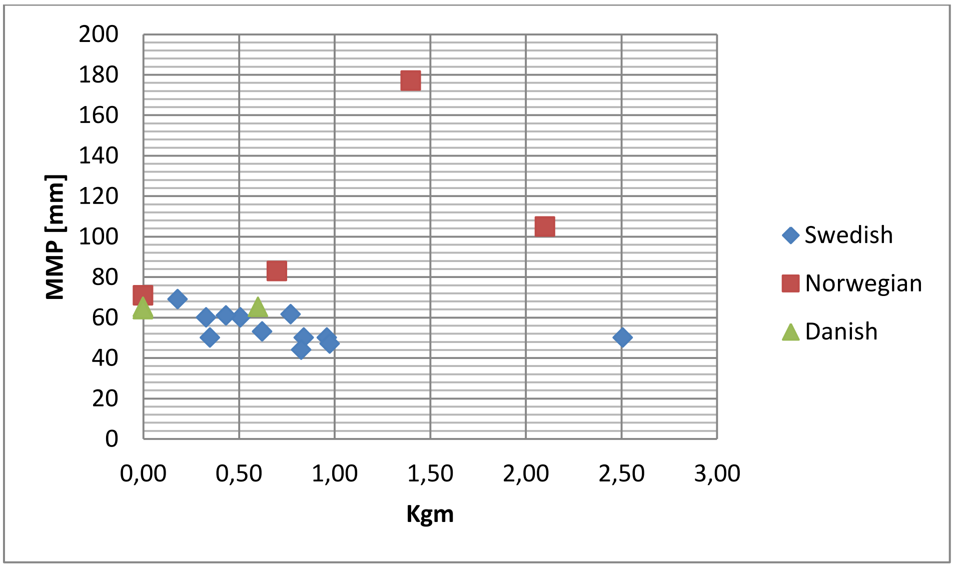

Figure 9-50. Calibration factor Kgm vs. MMP.

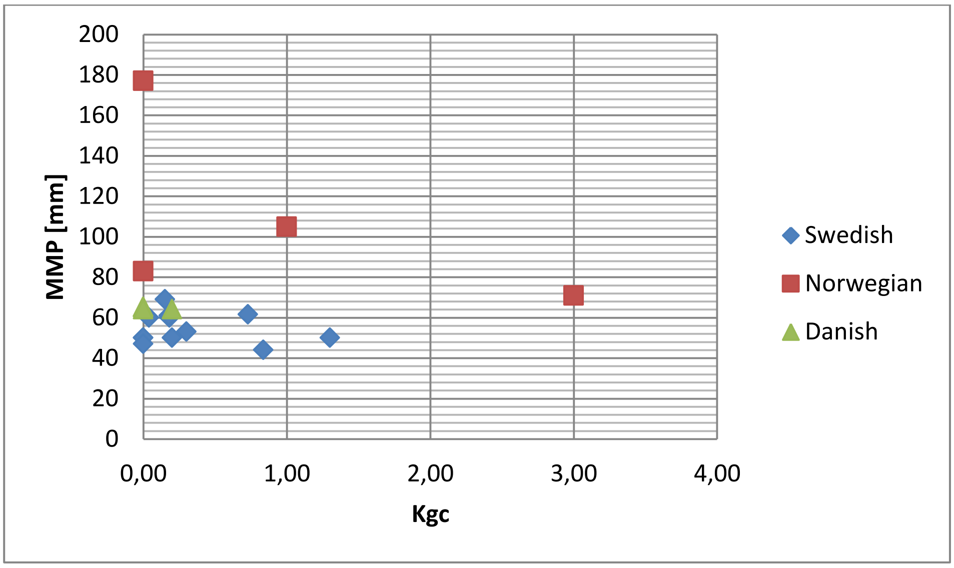

Figure 9-51. *Calibration factor K_{gc} vs. MMP.*

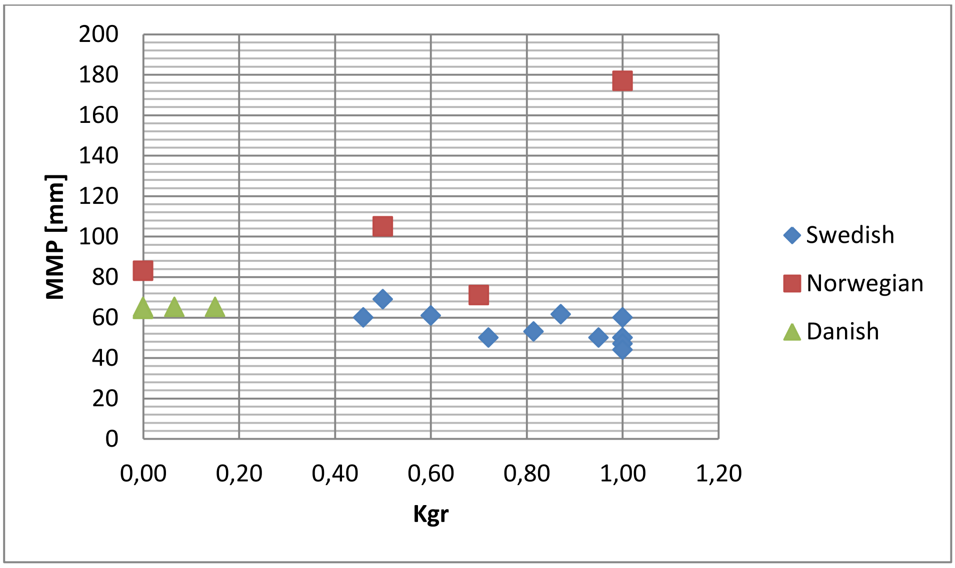

Figure 9-52. *Calibration factor Kgr vs. MMP.*

F.5 Evaluation of potential grouping of test sections

If any potential grouping of test sections should be suitable on any of the various input parameters there should be a clear grouping of the plotted values for the section specific calibration factors. As this is not the case it can be concluded that no clear grouping can be made for the test sections in regards to the evaluated section specific calibration factors.

Appendix G Country wise section specific calibration factors

In the table below the section specific calibration factors for each country is given as the weighted average after the test sections have been split into high and low heavy traffic as per Table 5-1:

Table 9-25. Country wise section specific calibration factors (weighted average of Table 9-24 in Appendix F).

Calibration factor[1)]	**Sweden**			**Norway**			**Denmark**		
	Average	**High heavy traffic (≥ 1.000)[2)]**	**Low heavy traffic (< 1.000)[2)]**	**Average**	**High heavy traffic (≥ 150)[2)]**	**Low heavy traffic (< 150)[2)]**	**Average**	**High heavy traffic (≥ 2.000)[2)]**	**Low heavy traffic (< 2.000)[2)]**
K_{cia}	0.74	0.99	0.69	0.74	0.74	0.74	0.74	0.74	0.74
K_{pp}	0.04	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00
K_{rid}	0.01	0.09	0.10	0.05	0.00	0.10	0.00	0.00	0.00
K_{rst}	4.85	5.66	4.69	9.70	16.00	3.40	4.82	1.55	7.00
K_{gm}	0.78	0.48	0.84	1.05	0.35	1.75	0.12	0.00	0.20
K_{gs}	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
K_{gc}	0.33	0.44	0.30	1.00	1.50	0.50	0.04	0.10	0.00
K_{gr}	0.83	0.69	0.85	0.55	0.35	0.75	0.04	0.00	0.07

[1)] Values for standard calibration factors can be seen in Appendix D.
[2)] Split between high and low heavy traffic as per Table 5-1.

Appendix H Validation of '3xP Nordic' software

Validation of the '3xP Nordic' software has been carried out by comparing the output from analysis of different pavement sections with the HDM-4 program. The following distress types have been used for the validation:

- Predicted development of all structural cracking (ACA)
- Predicted development of rutting
- Predicted development of roughness expressed as IRI

The following test sections have been used for the validation, which sections have a large variation in age, subgrade strength, amount of heavy traffic and conditions at the start of the analysis, see relevant tables in Appendix A and Appendix C.

- Äppelbo (RV71), Sweden, various subsections
- Tvååker (E6), Sweden, various subsections
- Trondheim, (E6), Norway
- Tromsø, (E8), Norway

H.1 Predicted development of all structural cracking (ACA)

The results for the predicted development of all structural cracking for the above test sections can be seen in Figure 9-53 to Figure 9-58:

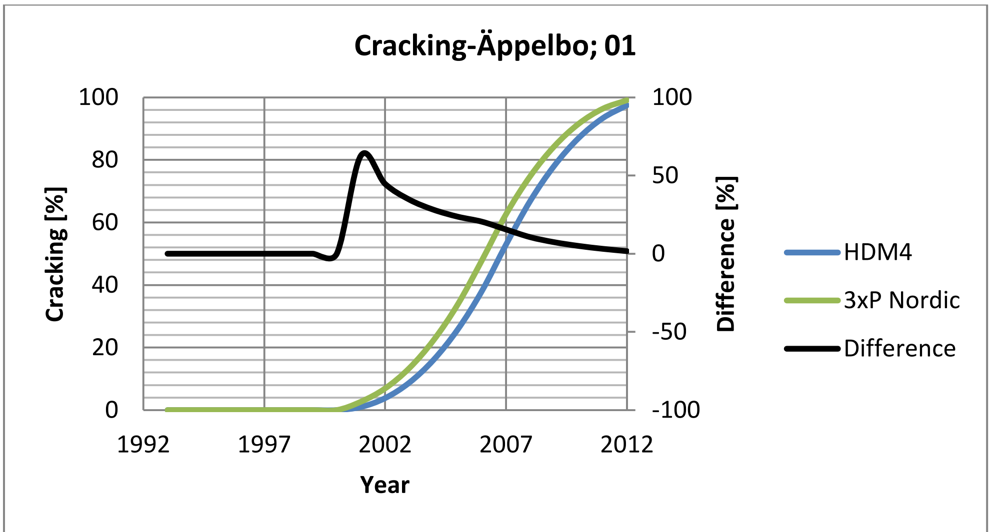

Figure 9-53. Comparison of predicted development of cracking, Äppelbo (RV71), subsection 1, Sweden.

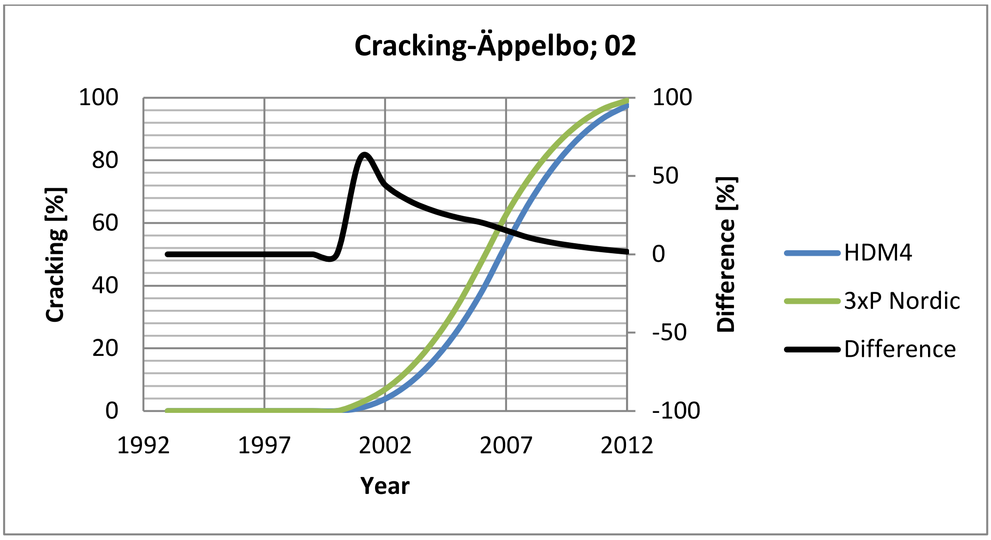

Figure 9-54. *Comparison of predicted development of cracking, Äppelbo (RV71), subsection 2, Sweden.*

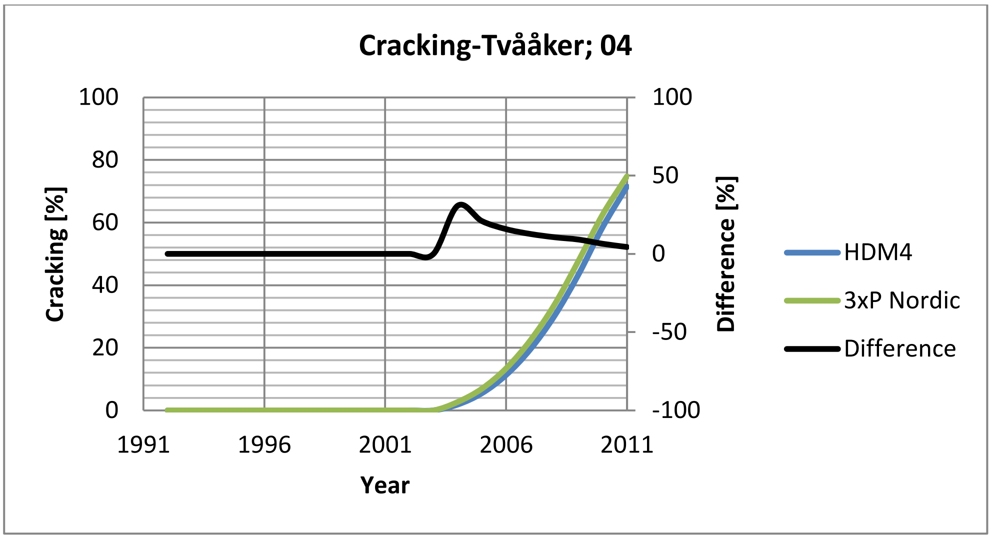

Figure 9-55. *Comparison of predicted development of cracking, Tvååker (E6), subsection 4, Sweden.*

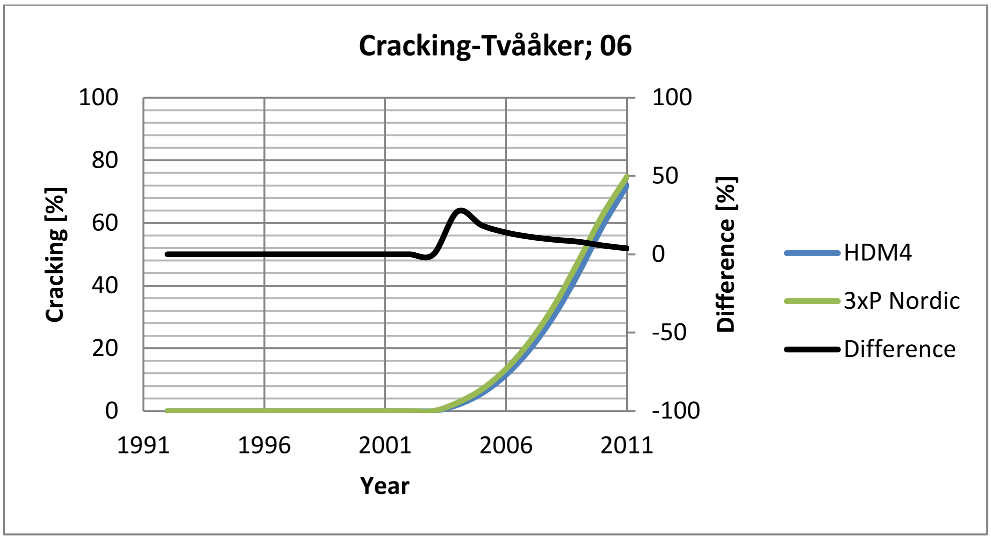

Figure 9-56. *Comparison of predicted development of cracking, Tvååker (E6), subsection 6, Sweden.*

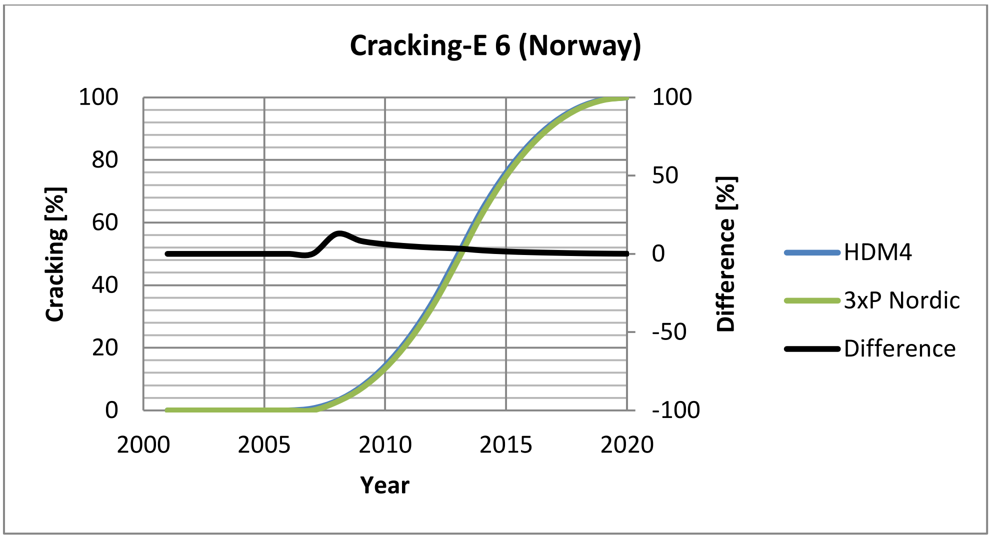

Figure 9-57 *Comparison of predicted development of cracking, Trondheim (E6), Norway.*

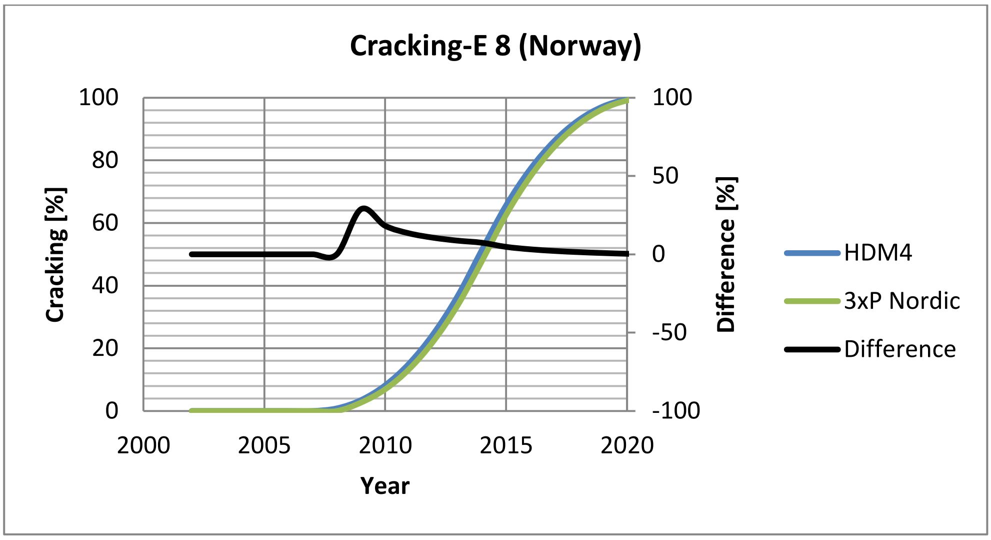

Figure 9-58. Comparison of predicted development of cracking, Tromsø (E8), Norway.

From the figures above it can be seen that there is a difference in the all structural cracking (ACA) at the time of initiation of cracking, but then drops and results in comparable results.

The difference at the time of initiation of cracking appear to be large, when regarded relatively, but is small as an absolute number. If e.g. the HDM-4 program predicts 1% of cracking in the first year and the '3xP Nordic' software predicts 2%, then the relative difference is 100%, whereas the absolute difference is 1%, which is well within the expected accuracy of measurement at network level.

H.2 Predicted development of rutting

The results for the predicted development of rutting for the above test sections can be seen from Figure 9-59 to Figure 9-64.

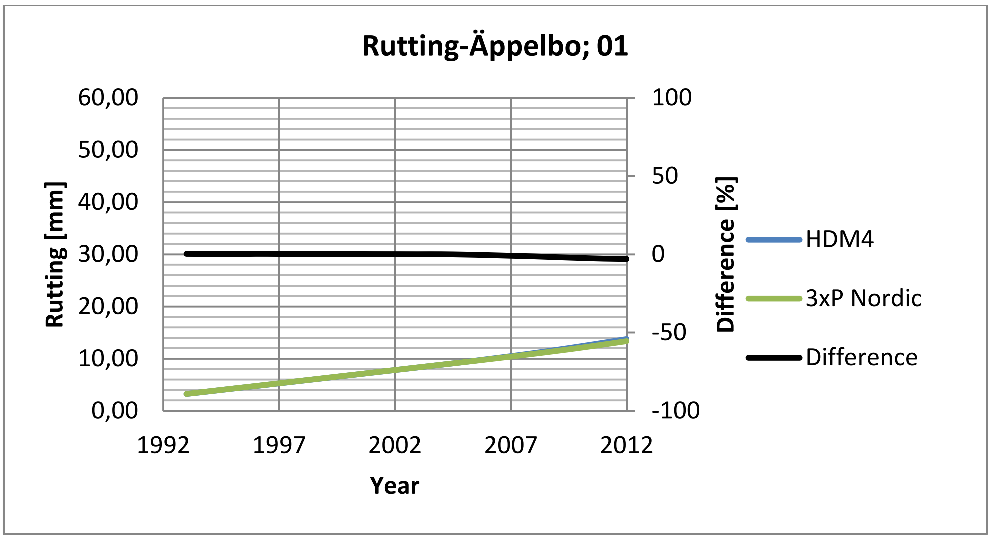

Figure 9-59. Comparison of predicted development of rutting, Äppelbo (RV71), subsection 1, Sweden.

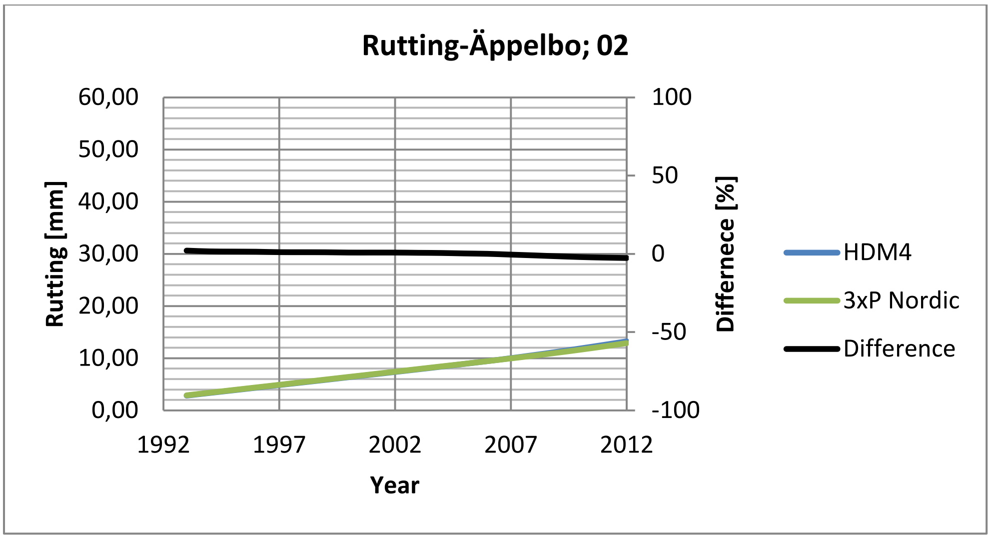

Figure 9-60. Comparison of predicted development of rutting, Äppelbo (RV71), subsection 2, Sweden.

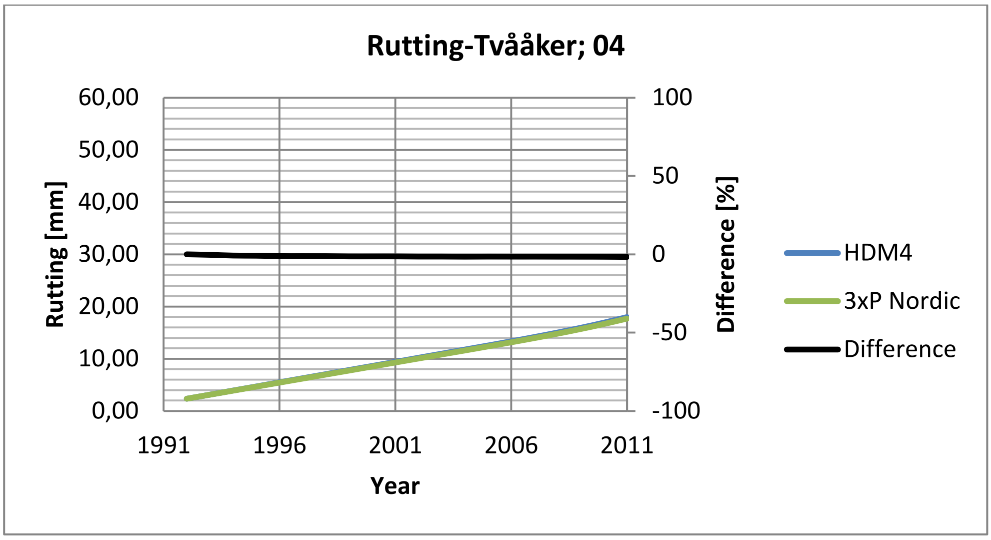

Figure 9-61. Comparison of predicted development of rutting, Tvååker (E6), subsection 4, Sweden.

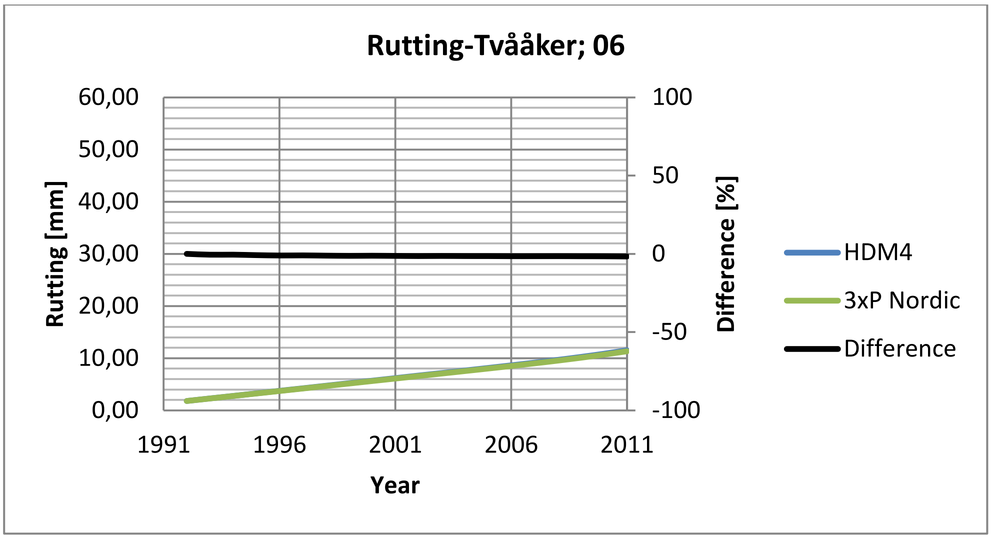

Figure 9-62. Comparison for predicted development of rutting, Tvååker (E6), subsection 6, Sweden.

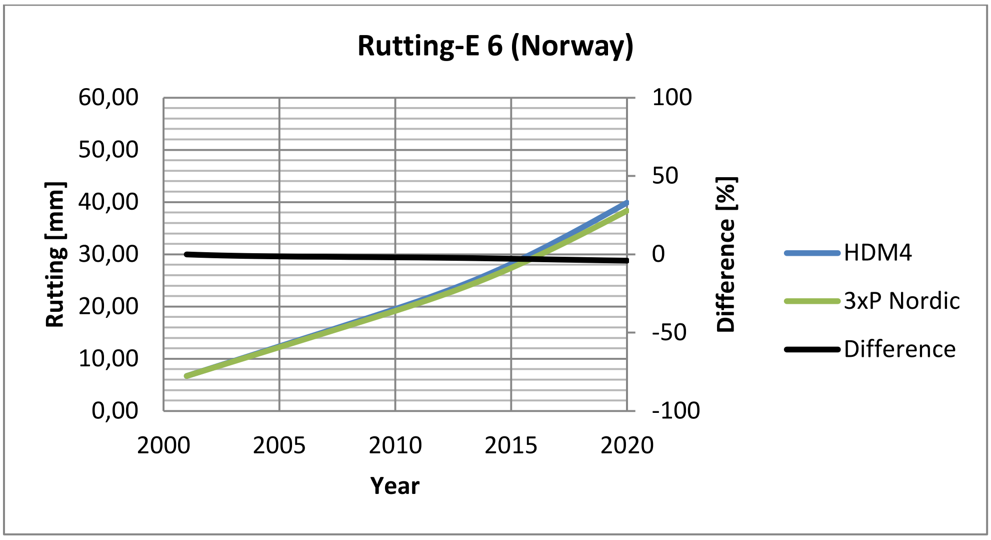

Figure 9-63. Comparison for predicted development of rutting, Trondheim (E6), Norway.

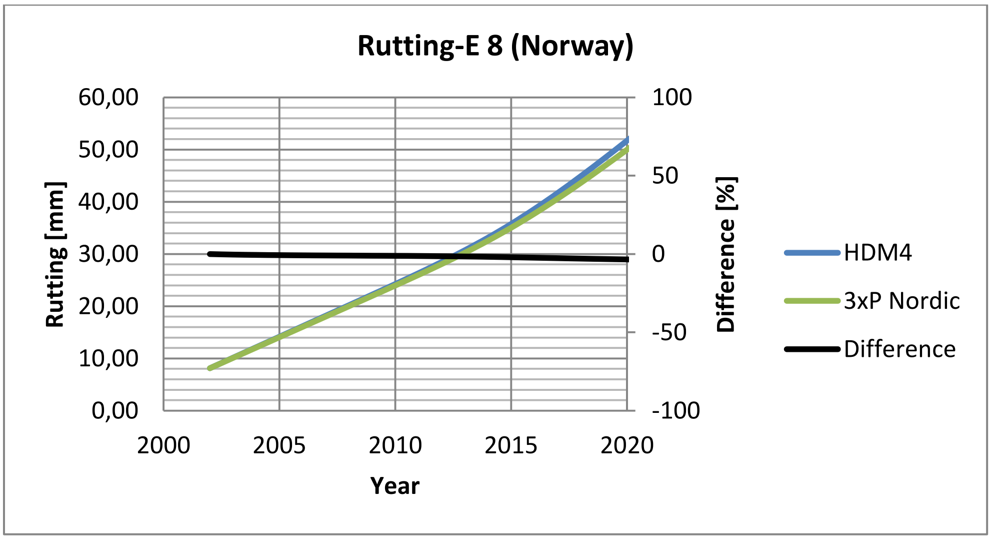

Figure 9-64. Comparison for predicted development of rutting, Tromsø (E8), Norway.

From the figures above it can be seen that the difference in the predicted rutting from the HDM-4 program and the '3xP Nordic' software is generally within a few percent and less than 5% over a 20 year period.

H.3 Predicted development of roughness

The results from the predicted development of roughness expressed as IRI for the above test sections can be seen from Figure 9-65 to Figure 9-70.

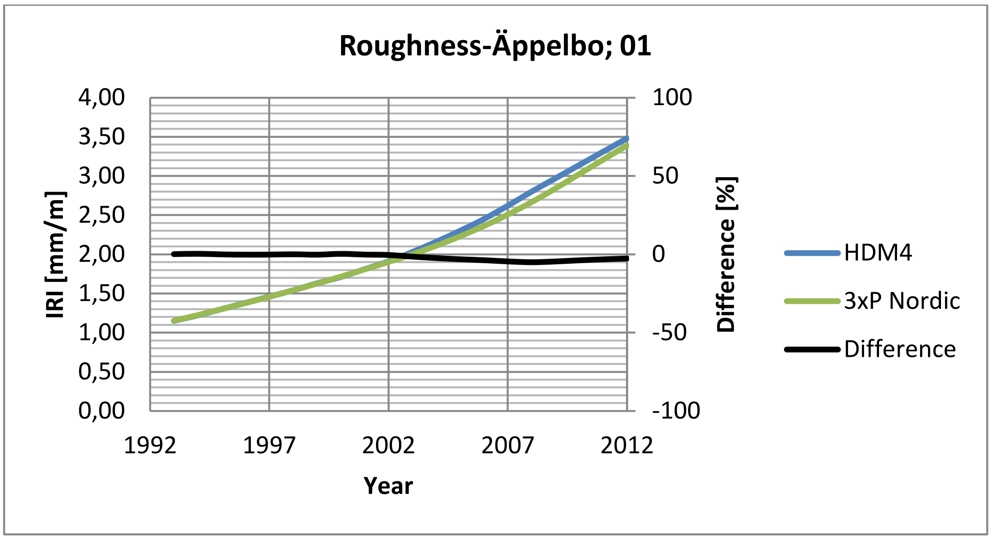

Figure 9-65. *Comparison of predicted development of IRI, Äppelbo (RV71), subsection 1, Sweden.*

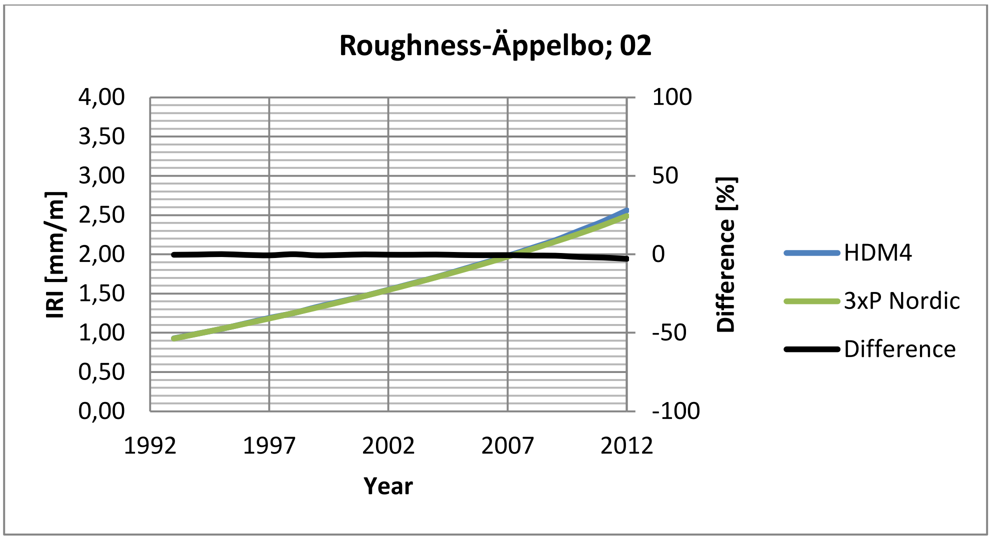

Figure 9-66. *Comparison for predicted development of IRI, Äppelbo (RV71), subsection 2, Sweden.*

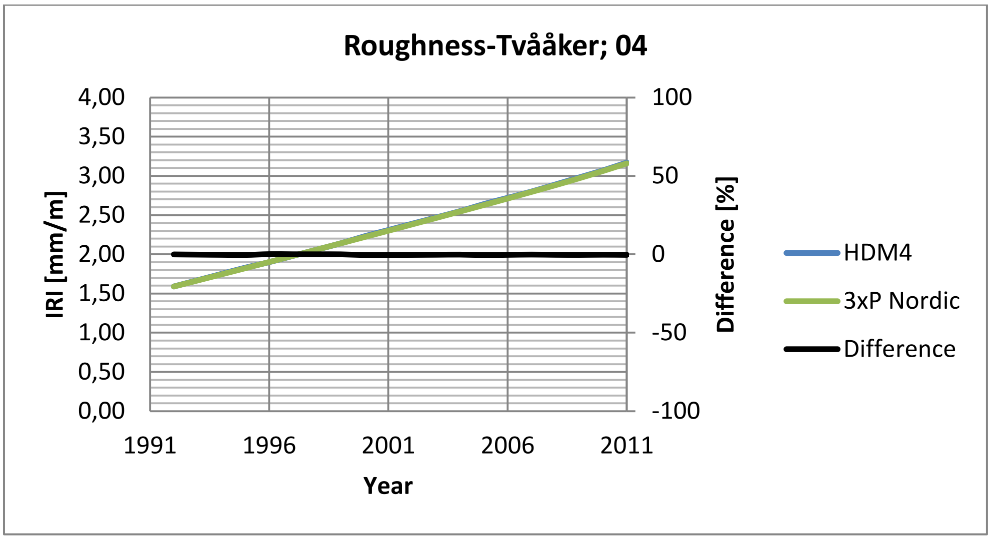

Figure 9-67. Comparison for predicted development of IRI, Tvååker (E6), subsection 4, Sweden.

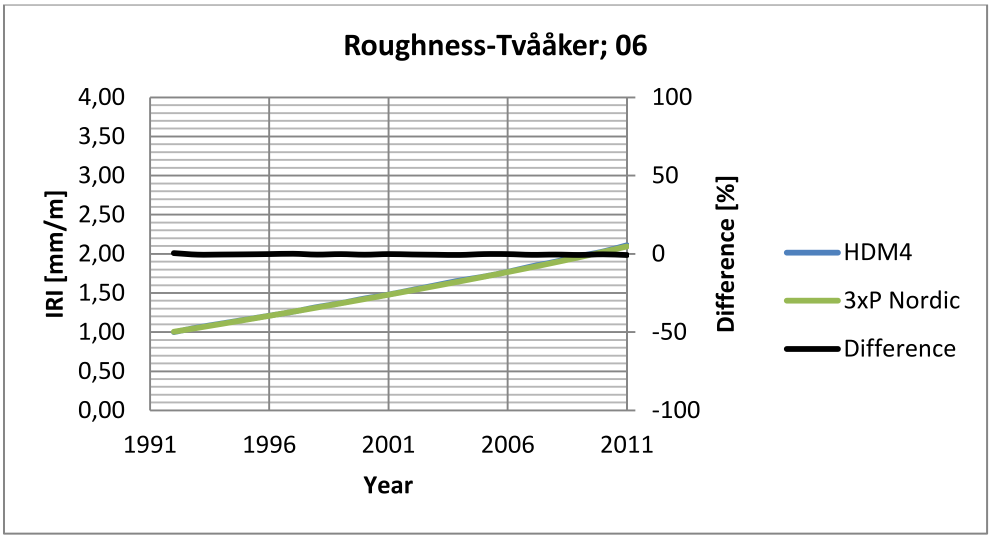

Figure 9-68. Comparison for predicted development of IRI, Tvååker (E6), subsection 4, Sweden.

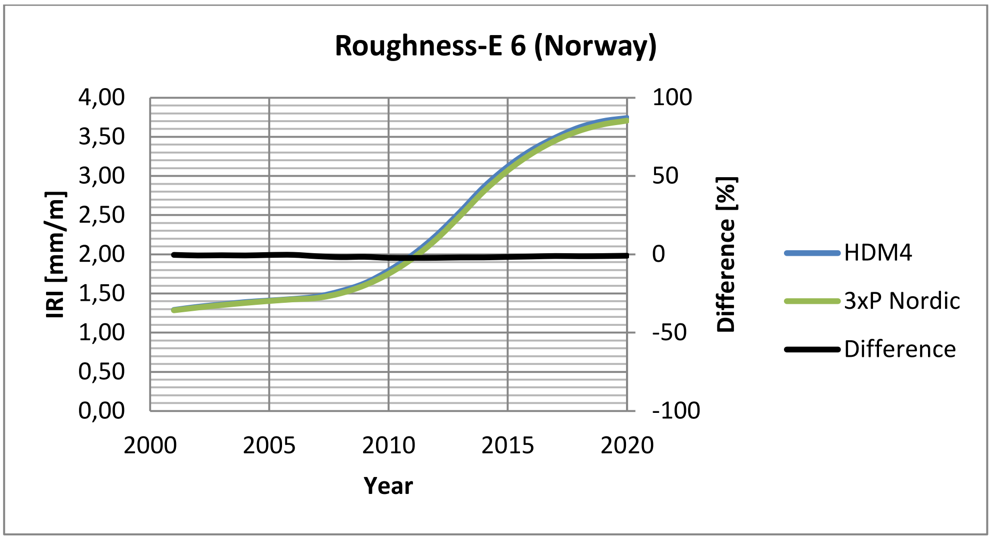

Figure 9-69. Comparison for predicted development of IRI, Trondheim (E6), Norway.

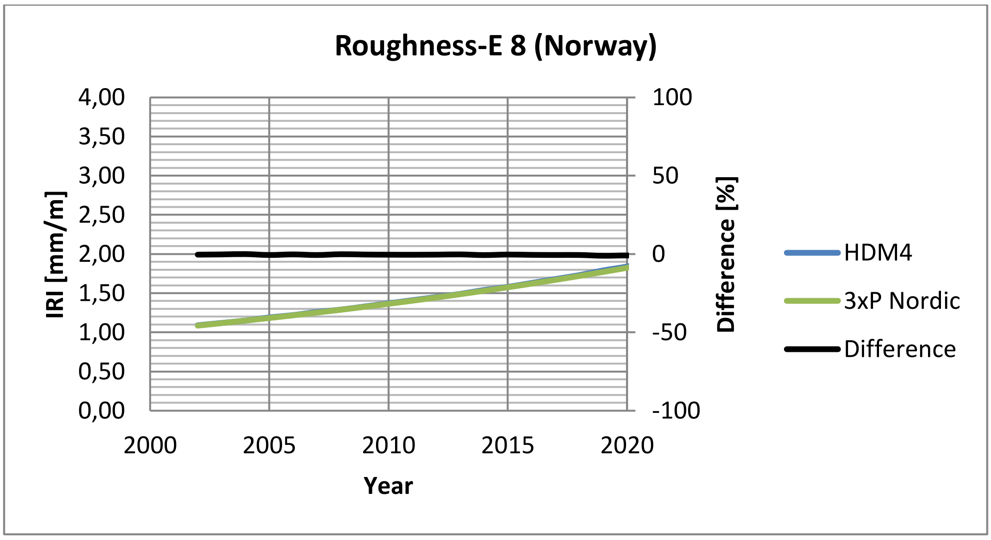

Figure 9-70. Comparison for predicted development of IRI, Tromsø (E8), Norway.

From the figures above it can be seen that the difference in the predicted roughness from the HDM-4 program and the '3xP Nordic' software in general is very small.

H.4 Summary of validation

In the table below the absolute differences between the HDM-4 program and the '3xP Nordic' software is shown as well as the fit between the two curves expressed as a R^2-value:

Table 9-26. Overview of difference between the HDM-4 program and the '3xP Nordic' software.

Section	All structural cracking			Rutting			Roughness		
	Max. diff. [%]	Average diff. [%]	Curve fit [R^2]	Max. diff. [mm]	Average diff. [mm]	Curve fit [R^2]	Max. diff. [mm/m]	Average diff. [mm/m]	Curve fit [R^2]
Äppelbo -01	9.80	3.33	0.99	0.40	0.07	1.00	0.13	0.05	1.00
Äppelbo -02	9.67	3.28	0.99	0.34	0.02	1.00	0.07	0.01	1.00
Tvååker -04	4.36	1.12	1.00	0.29	0.14	1.00	0.01	0.01	1.00
Tvååker -06	3.83	0.99	1.00	0.19	0.09	1.00	0.02	0.01	1.00
E6	4.64	0.55	1.00	1.55	0.54	1.00	0.06	0.03	1.00
E8	3.54	1.16	1.00	1.96	0.61	1.00	0.02	0.01	1.00

From the table above the '3xP Nordic' software is deemed to produce similar results compared to the HDM-4 program in regards of predicting pavement performance.

Appendix I Calibration of the duration of the dry season (d)

In the HDM-4 program the duration of the dry season is related to the moisture class, where a calibration factor d is the fraction of the length of dry season:

$$d = \frac{duration\ of\ dry\ season\ (month)}{12\ month}$$

In HDM-4 this results in the following:

Table 9-27. Duration of dry season in months and resulting value of d.

Moisture class	Duration of dry season [Months]	d [-]
Per-humid	1.2	0.10
Humid	3.0	0.25
Sub-humid	6.0	0.50
Semi-arid	9.0	0.75
Arid	10.8	0.90

The duration of the dry season d has an effect on the prediction of the development of the Structural Number (SNP) as give below:

$$SNP = f_s \times SNP_d$$

$$f_s = \frac{f}{\left[(1-d)+d \times f^p\right]^{1/p}}$$

$$f = K_f \times \left\{1 - \frac{\left[1-10^{a_0 \times MMP}\right]}{a_1} \times (1 + a_2 \times DF_a) \times (1 + a_3 \times ACRA_a + a_4 \times APOT_a)\right\}$$

where: 'SNP' is the average annual adjusted Structural Number of the pavement.

'f_s' is a calibration factor to convert SNP_d to SNP.

'SNP_d' is the Structural Number in the dry season and is based on either FWD measurement, Benkelman Beam or layer coefficients.

'f' is the ratio between the Structural Number in the wet and the dry season (SNP_{wet} / SNP_{dry}).

'd' is the duration of dry season in months as a fraction of the year.

'p' is the exponent of SNP specific to the appropriate deterioration model (p = 5.00 for flexible pavement structures according to HDM-4).

'K_f' is the calibration factor for wet/dry season SNP ratio (range from 0.1 to 10 according to the HDM-4).

'a_x' is the layer coefficients for the materials in the pavement structure.

'MMP' is the Mean Monthly Precipitation in mm.

'DF_a' is the drainage factor at the start of the analysis year.

'$ACRA_a$' is the total area of cracking at the start of the analysis year (% of total carriageway area).

'$APOT_a$' is the total area of potholes at the start of the analysis year (% of total carriageway area).

The investigation of the calibration factor d has shown that using the values of d in Table 9-27 over causes the '3xP Nordic' software to produce SNP values which are deviating from the HDM-4 program. A d value of 0.57 seems to be fitting for the Semi-Arid sections investigated. However for Humid and Sub-humid sections there is a clear tendency that d should be less than 0 to provide similar results to the HDM-4 program in regards of SNP, but it has not been possible to find a value of d, which brings the '3xP Nordic' software to produce similar results.

The calibration process in PPM2 has therefore been carried out with a permanent d value of 0.57 regardless of moisture class for the given section.

In the table below the calculated SNP based on the HDM-4 program (d value based on moisture class) and the '3xP Nordic' software (d value of 0.57 regardless of moisture class) are given:

Table 9-28. Value of SNP for the first year of the analysis.

Section/subsection	Moisture class	SNP (HDM-4)[1)]	SNP (3xP Nordic)[2)]	Deviation [%]
RV34, subsection 1, Målilla, Sweden	Semi-Arid	5.27	5.27	0
RV60, subsection 1, Borlänge, Sweden	Semi-Arid	8.23	8.24	0.12
RV60, subsection 8, Borlänge, Sweden	Semi-Arid	8.28	8.29	0.12
RV71, subsection 1, Äppelbo, Sweden	Semi-Arid	6.00	6.00	0
RV71, subsection 1, Äppelbo, Sweden	Semi-Arid	5.91	5.91	0
RV5, Norway	Humid	4.97	5.28	5.87
E39, Norway	Sub-Humid	5.58	5.66	1.41
E6, Norway	Sub-Humid	9.36	9.60	2.50
E8, Norway	Sub-Humid	5.41	5.50	1.64

[1)] d value based on moisture class.
[2)] d value of 0.57 regardless of moisture class.

Appendix J Detailed description and worked example of the calibration process

This appendix deals with the calibration process used in throughout this report.

J.1 Calibration process

The deterioration/distress parameters used in the calibration of the '3xP Nordic' software are summarised below:

- Cracking
- Rutting
- Roughness

In the PPM project in 2010 the calibration of the above mentioned parameters was carried out in the following steps:

- Step 1: Determine calibration factors directly from the historical data
- Step 2: Calibrate predicted development of cracking to historical data
- Step 3: Calibrate the predicted development of rutting to historical data
- Step 4: Calibrate the predicted development of roughness to historical data

During the PPM project in 2010 it was found that some calibration factors did not have any effect on the deteriation models. These calibration factors were therefore excluded from the calibration process and standard values were assigned for these factors. It was furthermore found during the PPM project in 2010 that development of cracking (Step 2) could not be calibrated from the historical data, as these did not distinguish bewteen type of cracks. As a consequence the methodology used in the calibration process in PPM2 was modified to include the following steps:

- Step 1: Determine calibration factors directly from the historical data (Evaluation of K_{cia})
- Step 3: Calibrate the predicted development of rutting to historical data
- Step 4: Calibrate the predicted development of roughness to historical data

J.2 Worked example

In the following the calibration process are described in details as a worked example. The worked example has been carried out for the Swedish national highway 60 (RV60) located close to Borlänge. Input parameters for the worked example can be found in the main text of the PPM2 and are summarised below.

As a supplement, the '3xP Nordic' Software also includes examples showing the input parameters in the different steps of the calibration.

J.2.1 Evaluation of input parameters used in calibration process

General input parameters

In the tables below the general input parameters used in the calibration process of RV60-Borlänge are summarized:

Table 9-29. Climate conditions (Extract of Table 9-1 in Appendix A).

Section	Mean Monthly Precipitation [mm]	Moisture class [-]	Temperature class [-]
RV60	50	Semi-Arid	Cool

Climatic input values for the '3xP Nordic' software are determined solely based on the Moisture class and temperature class shown in the table above.

Table 9-30. Pavement structure and traffic (Extract of Table 9-5 in Appendix A).

Section	ESALs per year	Surface thickness [mm]
RV60	167,535	130

All other standard input parameters used in the calibration process of the '3xP Nordic' software are summarized in Table 9-9 in Appendix B and in Appendix D. For re-working this example, section specific parameters for RV60 can be found in Appendix C in Table 9-10 and 9-11.

Specific input parameters for step 1 (Evaluation of K_{cia})

The following tables are summarizing the historical data and other input parameters used for calculating the K_{cia} calibration factor:

Table 9-31. Historical cracking data (Crack index, Si) for each subsection (From LTPP database).

Subsection	1	2	3	4	5	6	7	8	9	10
1991	0.0	0.0	0.0	0.0	0.0	12.5	0.0	1.5	4.5	0.0
1992	7.5	5.0	16.0	31.0	49.0	53.0	31.5	15.0	28.5	4.5
1993	17.0	16.0	19.5	64.5	121.5	77.0	107.0	42.0	47.0	39.0
1994	38.5	36.5	23.00	105.0	219.5	147.5	154.5	62.0	94.0	67.0
ICA[1)]	7	7	7	7	7	6	7	6	6	7

[1)] RV60 was constructed in 1985 and cracking data indicate initiation of cracking in 1991 or 1992 for each subsection. The time to initiation of cracking (ICA) is therefore determined as being 6 or 7 years for RV60.

Table 9-32. Standard values for calculation of K_{cia} (From Table 9-17 in Appendix E).

Parameter	**Value[1)]**
CDS	1.00[1)]
CRT	0.00[1)]
a_0	4.21[1)]
a_1	0.14[1)]
a_2	-17.10[1)]

[1)] Standard values used in HDM-4 program for flexible pavement structures.

In the '3xP Nordic' the time to initiation of all structural cracking is given by the following equation:

$$ICA = K_{cia} \times \left(CDS^2 \times a_0 \times EXP^{\left(a_1 \times SNP + a_2 \times \left(\frac{YE4}{SNP^2}\right)\right)} + CRT \right)$$

where: 'ICA' is the time to initiation of all structural cracking in years.

'CDS' is the construction defect rating for bituminous surfacing.

'a_x' is the layer coefficients for the materials in the pavement structure.

'SNP' is the average annual adjusted Structural Number of the pavement.

'YE4' is the annual number of ESALs (millions/lane).

'CRT' is the cracking retardation time due to maintenance in years.

Based on the equation above the section specific calibration factor K_{cia} has been calculated from the historical data and input values presented in Table 9-32 and Table 9-33:

Table 9-33. Section specific values for calculation of K_{cia} for RV60.

Section	Subsection	YE4[1)] [mill./lane]	Centre deflection, d_0[2)] [microns]	SNP[3)] [-]	Measured ICA[4)] [years]	Calculated K_{cia}
Borlänge RV60	1	0.168	218	8.35	7	0.54
	2	0.168	218	8.35	7	0.54
	3	0.168	225	8.20	7	0.55
	4	0.168	214	8.45	7	0.53
	5	0.168	204	8.70	7	0.51
	6	0.168	160	10.16	6	0.36
	7	0.168	196	8.93	7	0.49
	8	0.168	216	8.40	6	0.46
	9	0.168	253	7.60	6	0.52
	10	0.168	245	7.77	7	0.59

1) From Table 9-30 in millions.

2) From LTPP database, based on FWD measurements from 1991.

3) The Structural Number (SNP) can be determined based on e.g. Falling Weight Deflectometer (FWD) measurements as:

$$SNP = 3.2 \times \left(\frac{d_0}{1.000}\right)^{-0.63}$$

where: 'd_0' is the centre deflection in microns.

4) Determined from historical data, see Table 9-31.

Specific input parameters for step 3-4 (Predicted development of rutting and roughness)

Rutting and roughness measurements have been performed each year from 1991 to 1999. Measurements from 1991 and 1992 have however been omitted from the calibration process since the rutting measurements in these years are much higher than the measurements from 1993 and 1994. Measurements from 1998 and 1999 have also been omitted since an overlay was construction during 1997.

Historical data for Borlänge-RV60 in form of measured rutting and roughness are summarised in the tables below:

Table 9-34. Historical rutting data for each subsection of RV60 (From LTPP database).

Subsection	1	2	3	4	5	6	7	8	9	10
1993	3.83	3.85	4.33	3.53	5.05	4.70	5.20	4.00	4.50	4.55
1994	4.20	5.33	4.68	3.98	5.08	4.83	5.98	4.63	5.28	5.33
1995	5.75	6.60	6.00	5.03	6.58	6.30	6.85	5.70	6.25	6.00
1996	6.38	6.93	6.33	5.45	6.70	6.53	7.78	6.25	6.78	6.98
1997	7.43	7.68	7.13	6.23	8.48	7.83	8.35	7.68	8.00	7.78

Table 9-35. Historical roughness data for each subsection of RV60 (From LTPP database).

Subsection	1	2	3	4	5	6	7	8	9	10
1993	2.34	1.79	2.99	1.93	2.02	1.75	1.81	2.41	1.97	2.73
1994	2.44	1.74	3.17	2.04	2.11	1.56	1.88	2.56	1.93	2.77
1995	2.33	1.79	3.21	2.09	2.18	1.73	1.91	2.55	1.94	2.99
1996	2.58	1.88	3.29	2.01	2.22	1.80	1.96	2.73	2.11	3.19
1997	2.60	1.89	3.32	2.07	2.21	1.94	1.98	2.86	2.20	3.23

J.2.2 Calibration process

Calibration of K_{cia} (Step 1)

Using the input values presented in Table 9-32 and Table 9-33 above K_{cia} has been calculated for each subsection, see Table 9-33. Using the calculated K_{cia} values in the '3xP Nordic' software does however not result in the correct year for initiation of cracking (ICA) based on the associated equation. It is therefore necessary to calibrate K_{cia} to get the correct year for initiation of cracking.

The issue of '3xP Nordic' not given the correct year for initiation of cracking is illustrated in the following. As an example subsection 7 of RV60 has been used. The following figures illustrate the outcome from the '3xP Nordic' using the calculated K_{cia} value (0.49) and the calibrated K_{cia} value (0.46). From the figures below it can be seen that initiation of cracking starts in 1993 for the calculated K_{cia} value, compared with the historical data this is incorrect as initiation of cracking should start in 1992, see Table 9-31. The K_{cia} value has therefore been calibrated so the initiation of cracking starts in 1992.

	Roughness	Structural number	All structural cracking	Wide cracking	Thermal cracking	Total cracking
	IRI	SNPK	ACA	ACW	ACT	ACRA
Year	[m/km]	[-]	[%]	[%]	[%]	[%]
1985	1.816077	8.814436	0	0	0	0
1986	1.827221	8.814436	0	0	0	0
1987	1.871141	8.814436	0	0	0	0
1988	1.913677	8.814436	0	0	0	0
1989	1.95482	8.814436	0	0	0	0
1990	1.994563	8.814436	0	0	0	0
1991	2.032898	8.814436	0	0	0	0
1992	2.069815	8.814436	0	0	0	0
1993	2.105324	8.810129	2.686534	0	0	2.686534
1994	2.139483	8.79128	6.919801	0	0	6.919801

Figure 9-71. Output from '3xP Nordic' for subsection 7 of RV60 (calculated K_{cia})

	Roughness	Structural number	All structural cracking	Wide cracking	Thermal cracking	Total cracking
	IRI	SNPK	ACA	ACW	ACT	ACRA
Year	[m/km]	[-]	[%]	[%]	[%]	[%]
1985	1.816077	8.814436	0	0	0	0
1986	1.827221	8.814436	0	0	0	0
1987	1.871141	8.814436	0	0	0	0
1988	1.913677	8.814436	0	0	0	0
1989	1.95482	8.814436	0	0	0	0
1990	1.994563	8.814436	0	0	0	0
1991	2.032898	8.814436	0	0	0	0
1992	2.069834	8.810129	2.686534	0	0	2.686534
1993	2.105436	8.79128	6.919801	0	0	6.919801
1994	2.139774	8.754719	13.40855	4.010528	0	13.40855

Figure 9-72. Output from '3xP Nordic' for subsection 7 of RV60 (calibrated K_{cia})

The table below shows the calculated and calibrated K_{cia} as well as the difference between the two.

Table 9-36. Calculated and calibrated values of K_{cia} for all subsections of RV60.

Section	Subsection	Calculated K_{cia}	Calibrated K_{cia}	Difference [%]
Borlänge RV60	1	0.54	0.50	7.41
	2	0.54	0.43	20.37
	3	0.55	0.51	7.27
	4	0.53	0.50	5.66
	5	0.51	0.48	5.88
	6	0.36	0.32	9.86
	7	0.49	0.46	6.12
	8	0.46	0.42	8.70
	9	0.52	0.48	7.69
	10	0.59	0.55	6.78

The calibrated K_{cia} values presented in the table above are used throughout the following calibration process in the worked example.

Calibration of predicted development of rutting and roughness (Step 3-4)

The following calibration factors have been calibrated with regards to rutting and roughness, given the best fit between the historical data and the outcome from the '3xP Nordic' software:

Table 9-37. Section specific calibration factors that can be determined as best fit based on historical data used in the calibration process.

Section specific calibra-tion factor	Parameter	Description
K_{pp}	Roughness	Calibration factor for the pothole progression model (generally used as 0).
K_{rst}	Rutting	Calibration factor for the rutting structural deterioration model.
K_{rid}	Rutting	Calibration factor for the rutting initial densification model.
K_{gm}	Roughness	Calibration factor for the environmental roughness model.
K_{gs}	Roughness	Calibration factor for the roughness model (structural contribution).
K_{gc}	Roughness	Calibration factor for the roughness model (cracking contribution).
K_{gr}	Roughness	Calibration factor for the roughness model (ravelling contribution).

The calibration of rutting and roughness is an iterative process, starting with calibration of the rutting progression (iteration 1) followed by calibration of the roughness progression (iteration 2), followed by re-calibration of the rutting progression and so on. The calibration process is continued until both the rutting and roughness give a good correlation between the historical data and the outcome from the '3xP Nordic' software. The required number of iterations for obtaining a good correlation between the historical data and the outcome from the '3xP Nordic' software can vary from subsection to subsection.

All calibration factors in the table above are ranked according to their effect on the rutting and roughness progression. The calibration of both rutting and roughness has in general been carried out changing the calibration factor ranked highest first followed by change of the factor with second highest effect and so on.

Note: When input are entered in the '3xP Nordic' software for these calibration steps, “Year of construction” are to be entered as “Year of analysis” minus 1.

In the following figures the calibration process of rutting and roughness has been illustrated for subsection 7 of RV60. Figure 9-73 below shows the correlation between the historical data and output from the '3xP Nordic' software applying standard values for all calibration factors. Figure 9-74 shows iteration 1 calibration of rutting and finally Figure 9-75 shows iteration 2 calibration of roughness.

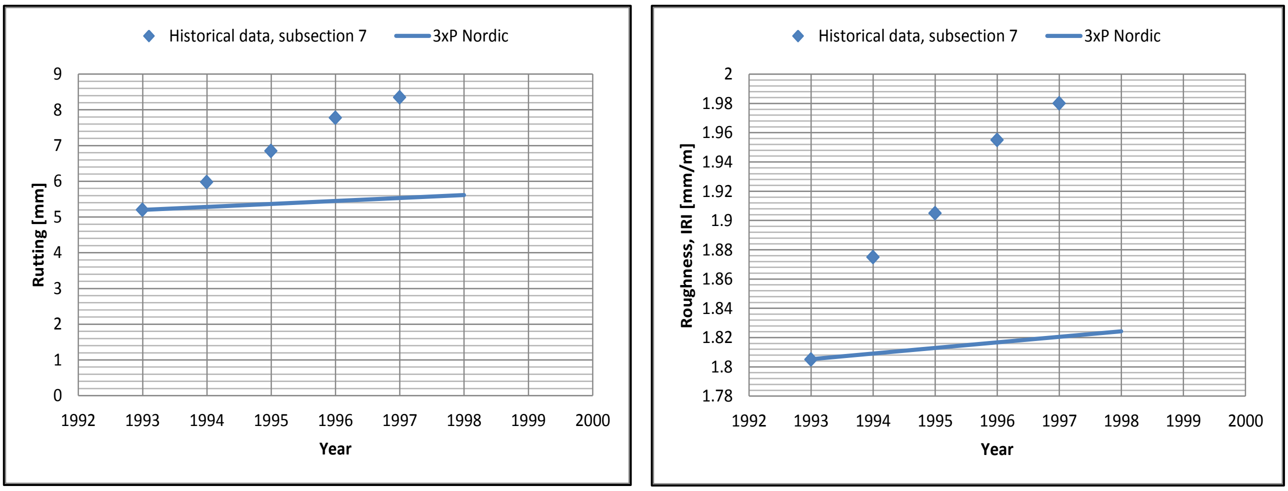

Figure 9-73. Predicted development of rutting and roughness using standard calibration factors of subsection 7 for RV60 (see values of section specific calibration factors in Table 9-38 below).

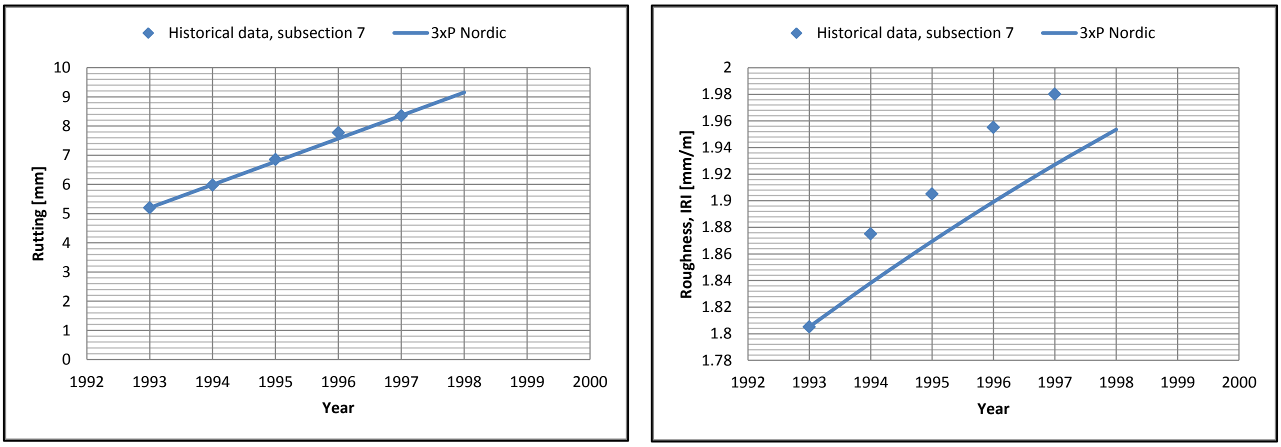

Figure 9-74. Predicted development of rutting and roughness in iteration 1 (calibration of rutting) of subsection 7 for RV60 (see values of section specific calibration factors in Table 9-38 below).

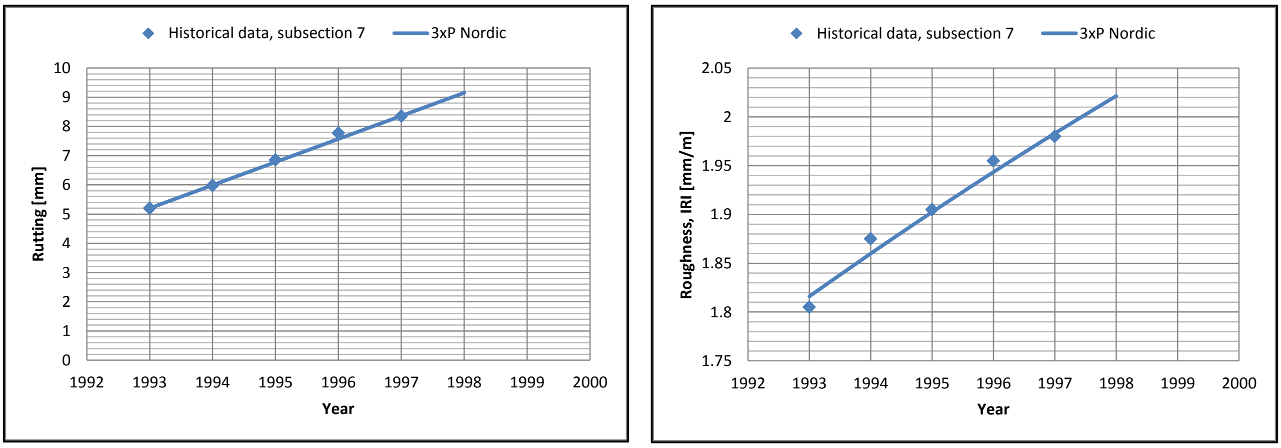

Figure 9-75. Predicted development of rutting and roughness in iteration 2 (calibration of roughness) of subsection 7 for RV60 (see values of section specific calibration factors in Table 9-38 below).

The following table summarises the calibration factors used for the different iterations of the calibration process.

Table 9-38. Calibration factors for each calibration phase of subsection 7 for RV60.

Calibration factor	Standard[1)]	Iteration 1[2)]	Iteration 2[3)]
K_{rst}	1.00	9.50	9.50
K_{rid}	0.00	0.00	0.00
K_{gm}	0.00	0.00	0.20
K_{gs}	1.00	1.00	1.00
K_{gc}	0.00	0.00	0.00
K_{gr}	1.00	1.00	1.00

[1)] Standard calibration factors from HDM-4 used as start values in the calibration process.
[2)] Calibration factors obtained from iteration 1 (calibration of rutting).
[3)] Calibration factors obtained from iteration 2 (calibration of roughness).

The following table summarises the calibration factors for all subsection of Borlänge-RV60. In addition the table contain average values for each calibration factor; these average calibration factors has been used in the evaluation of the overall calibration factors for Sweden.

Table 9-39. Summarised calibration factors for each subsection for Borlänge-RV60.

Section	Sub section	Calibrated values for each subsection							
		K_{cia}	K_{rid}	K_{pp}	K_{rst}	K_{gm}	K_{gs}	K_{gc}	K_{gr}
Borlänge-RV60	1	0.50	0.00	0.00	8.50	0.30	1.00	0.00	1.00
	2	0.43	0.00	0.00	10.0	0.00	1.00	0.00	1.00
	3	0.51	0.00	0.00	7.50	0.40	1.00	0.00	1.00
	4	0.50	0.00	0.00	7.00	0.20	1.00	0.00	1.00
	5	0.48	0.00	0.00	8.30	0.40	1.00	0.00	1.00
	6	0.32	0.00	0.00	9.00	0.10	1.00	0.00	1.00
	7	0.46	0.00	0.00	9.50	0.20	1.00	0.00	1.00
	8	0.42	0.00	0.00	9.00	0.80	1.00	0.00	1.00
	9	0.48	0.00	0.00	8.50	0.10	1.00	0.00	1.00
	10	0.55	0.00	0.00	8.00	1.00	1.00	0.00	1.00
Average		0.47	0.00	0.00	8.53	0.35	1.00	0.00	1.00

VEGAGERÐIN

Statens vegvesen

Vägverket

Vejdirektoratet