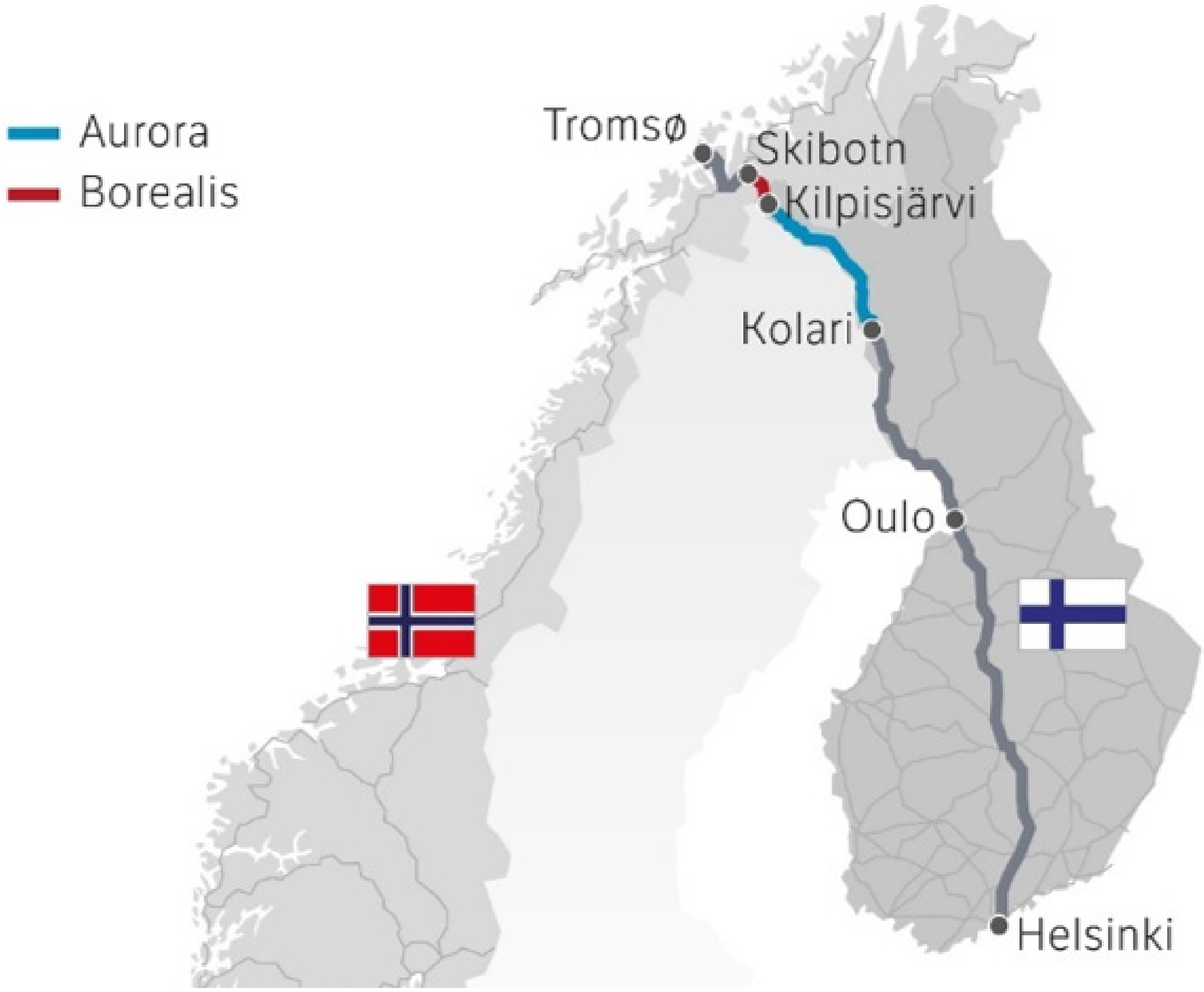
Drift og vedlikehold
Laboratorier og grunnboring
Laboratorium midt
20.05.2021

Statens vegvesen

Laser measurement of pavement condition

E8 Borealis, Skibotn – Border Finland

STATENS VEGVESENS RAPPORTER Nr. 712



Statens vegvesen

Statens vegvesens rapporter

Tittel
Dekketilstandsmålinger med laser på E8 Borealis – Spor, jevnhet, tverrfall og MPD

Undertittel
E8 Borealis, Skibotn – Riksgrense Finland, Troms- og Finnmark fylke

Forfatter
Trond Østen

Avdeling
Laboratorier og grunnboring

Seksjon
Laboratorium midt

Prosjektnummer
C13404

Rapportnummer
Nr. 712

Prosjektleder
Leif Jørgen Bakløkk

Godkjent av
Doreen Siebert

Emneord
IRI, spor, tekstur og lasermåling

Sammendrag

I forbindelse med testprosjektet E8 Borealis i 2019 ønsket Statens vegvesen å sammenligne ulike utstyr for måling av dekketilstand og få dokumentasjon på forskjeller og fordeler/ulemper for de ulike systemer. I tillegg er det ønskelig å få best mulig dokumentasjon av dekketilstand på E8 Skibotn – Riksgrense Finland i Troms og Finnmark fylke. Målingene er gjort både med tanke på overflatetilstand (spor, jevnhet, skader, tekstur og friksjon) og strukturell styrke/bæreevne og vegen oppbygging.

Denne rapporten er en dokumentasjon av de målinger som mer utført på dekketilstanden (spor, jevnhet, tverrfall og MPD). Rapporten sammenligner dataene fra de forskjellige utstyrene, og ser på forskjellene mellom hva de forskjellige tilbyderne tilbyr.

Antall sider 45

NPRA reports
Norwegian Public Roads Administration

Title
Laser measurement of pavement condition on E8 Borealis

Subtitle
E8 Borealis, Skibotn – Border Finland

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Approved by
Doreen Siebert

Key words
IRI, ruts, textur and laser measurement

Summary

In 2019, the Directorate of Public Roads in the Norwegian Public Roads Administration (NPRA) aimed to compare various equiptment's for measuring pavement condition and get documentation of the different systems. In addition, the NPRA was seeking the best possible documentation of pavement condition on the E8 test road, both with regard to surface condition (ruts, evenness, damage, texture, etc) and the structural strength/load-bearing capacity, as well as pavement structure. In total, five suppliers of measurement equipment were invited to accomplish measurements both with laser (scanners and bars), ground-penetrating radar, deflection measurements (load-bearing capacity with FWD, TSD or similar) and picture/video. This report is a documentation of the results from the surface investigations.

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Attachments

1. Roadscanners report from the measurements “RDSV surveys E8 Borealis 2019”
2. Ramboll’s report from the measurements “Pavement measurements at E8 in Troms Norway – Ramboll RST”
3. Lehmann + Partner report from the measurements “3D road condition monitoring on the arctic intelligent transport test ecosystem borealis on E8”
4. Terratec’s report from the measurements “Leveranserapport E8 Borealis”

1 Introduction

1.1 Background

In 2019, the Directorate of Public Roads in the Norwegian Public Roads Administration (NPRA) aimed to compare various equipment for measuring pavement condition and get documentation of the differences and advantages/disadvantages of different systems. In addition, the NPRA was seeking the best possible documentation of pavement condition on the E8 test road, both with regard to surface condition (ruts, evenness, damage, texture, etc.) and structural strength/load-bearing capacity, as well as pavement structure. In total, five suppliers of measurement equipment were invited to accomplish measurements both with laser (scanners and bars), ground-penetrating radar, deflection measurements (load-bearing capacity with FWD, TSD or similar) and pictures/video.

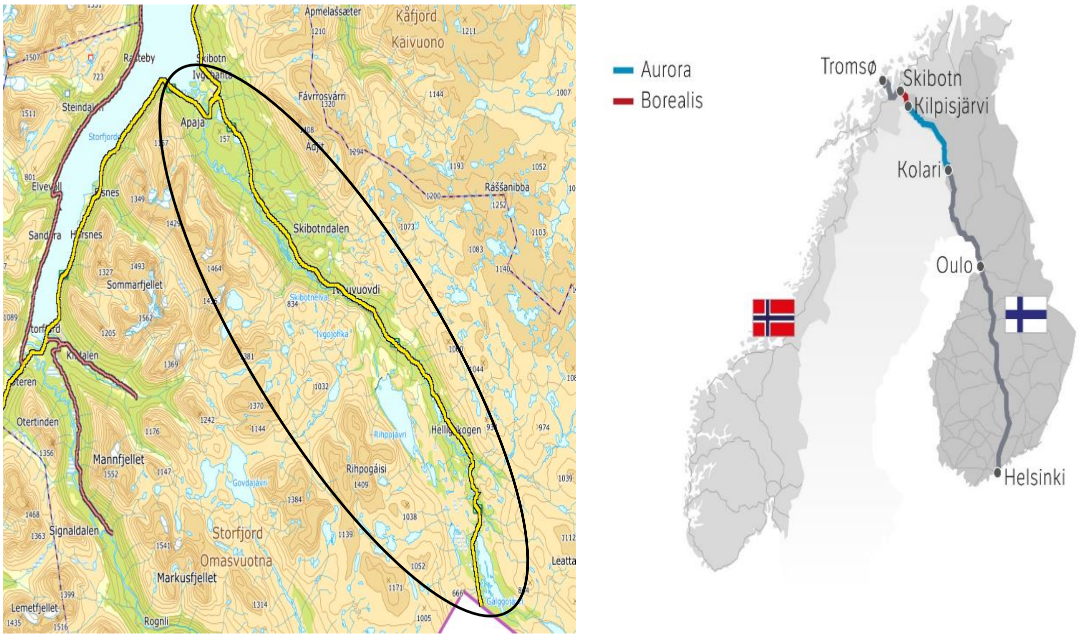


Figure 1: Overview map of the E8 Borealis project [1]

This report will focus on the surface conditions, rutting, evenness, texture and crossfall. The results from ground penetrating radar, bearing capacity with FWD, ditch depths, road structure are summarized in report 707 "*E8 Borealis, Måling av vegoverbygning, bæreevne og grøftedybder, E8 Skibotn–Riksgrense Finland, Troms- og Finnmark fylke*" [2], and should be put in context with the pavement measurements.

1.2 About the measurements

This report gives a summary of the findings for the surface condition (ruts, evenness, MPD and crossfall) from the different suppliers who took part in the study. In total, five suppliers partook in the measurements:

- Norwegian Public Roads Administration (NPRA)

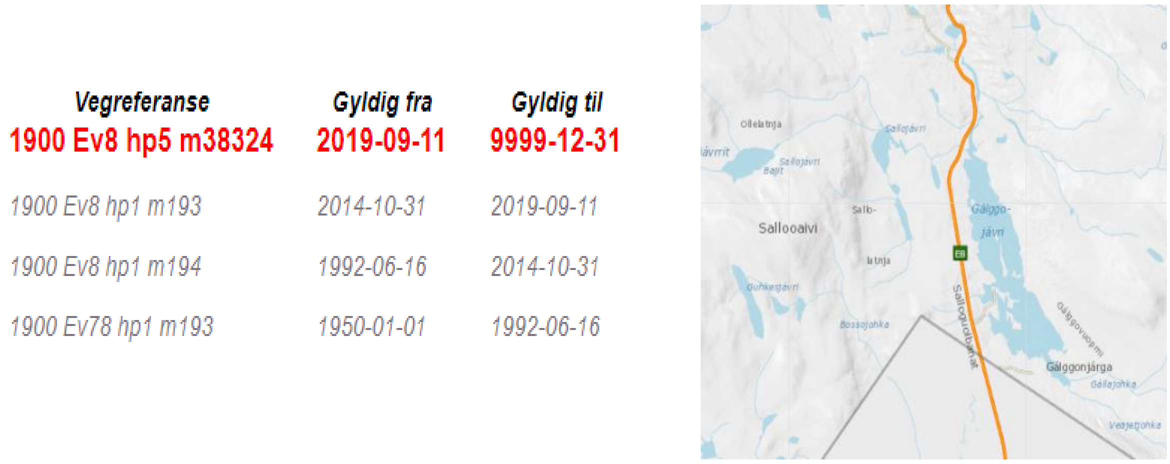
Laser measurement of pavement condition on E8 Borealis – Rutting, evenness, crossfall and MPD

- Roadscanners Oy
- Terra Tec AS
- Ramboll AS
- Lehmann + Partner

The measurements were conducted on August 20, 2019, on a section of the E8 from the Finnish border to E6 at Skibotn. The conducted road section is approximately 38 480 m long and was measured in both directions. The data from the measurements are not attached to this report but stored on NPRA's server (O:\DoV\Teknologi\CCA00 Teknologi\00 Prosjektarkiv\C13404 DekksysII_E8Borealis\Leveranser). Data can be procured on demand.

The following assumptions were given for the analysis of the collected data:

- All roads in Norway are divided into sections and meters. The NPRA measurements are synchronised with these, and the NPRA measurements have therefor been used as the blueprint in the comparisons. All other data are adjusted to the NPRA data.
- The road reference changed section number, and the direction was reversed on 11.09.2019. In this report the old reference is used (valid from 31.10.2014 to 11.09.2019). A comparison of old and new road references can be done here: https://labs.vegdata.no/vegrefendring/



Vegreferanse	Gyldig fra	Gyldig til
1900 Ev8 hp5 m38324	**2019-09-11**	**9999-12-31**
1900 Ev8 hp1 m193	2014-10-31	2019-09-11
1900 Ev8 hp1 m194	1992-06-16	2014-10-31
1900 Ev78 hp1 m193	1950-01-01	1992-06-16

Figure 2: Road reference history

- The direction from the Finnish border towards Skibotn is named "direction 1".
- The direction from Skibotn towards the Finnish border is named "direction 2".
- The distance (in meter) is increasing from the Finnish border towards Skibotn, for both directions.
- Because of the length of the section, only a small part of the section was used in the detailed analysis. The sub section from meter 18 600 – 20 600 was selected because one half of the section has an old road structure from the 70's (meter 18 600 – 19 600), while the other half was opened in 2014 (meter 19 600 – 20 600). This gave the opportunity to see if there were any differences between the results on an older and a newer road structure.

All but one supplier delivered data in 1-meter and 20-meter segments. The last supplier delivered data in 5-meter segments. Data from the 1-meter segments were used in the analysis. This was chosen because there were some deviations in what lengths are included in the 20-meter segments. Data for IRI are graphically presented as 100-meter average values.

It was not expected that the values of the data are exactly comparable, but the trend should give a good comparison. This is based on:

- Different methods of calculation (especially on rutting) regarding the wire lengths were used.
- Discrepancies in data that were included in the calculations (mostly for 20-meter segments)

1.3 Terms/definitions

The following terms are used in the report.

Rutting:	Rutting describes the transversal unevenness. Rutting is normally presented as median value in mm, over a 20-meter interval.
Evenness:	Evenness describes the lateral unevenness of a road and is classified after the international roughness index (IRI). IRI is usually presented as a median value in mm/m, over a 20-meter interval.
Crossfall:	Crossfall defines the slope of the road surface, measured laterally from the centre of the road toward the outside edge. Crossfall is positive when the outside edge is higher than the centre of the road. Crossfall is normally presented as a median value %, over a 20-meter interval.
Mean Profile Depth (MPD):	MPD describes the macro texture of the pavement, over a road section of 0,5-50 cm. A high value means that the pavement surface is coarse/rough. MPD is usually presented as median values in mm, over a 20-meter interval.

2 NPRA data

NPRA used a pavement profile system called ViaPPS, developed by ViaTech AS. The ViaPPS system meets the requirement for measuring on road surfaces given by the NPRA and the following standards:

- ASTM E-1448-92
- European Standard – Road and Airfield surface characteristics EN 13036-8

The ViaPPS system uses a 360° laser scanner, to create a high-resolution 3D point cloud and takes high-resolution pictures each 10-20 m. NPRA uses the Z+F PROFILER® 9012 laser scanner, with 119-meter range [3].

Rutting in Norway is calculated with different methods based on the width of the lane. The used methods are:

- Ridge height method
- Sliding wire method
- Sliding wire method with curve correction

The specifications of each method can be read in "R211 Felthåndbok" [4]. Each of these methods are also used to calculate the crossfall. The data are presented as median values over 20 m.

On E8, NPRA would normally use the ridge height method. However, since most of the other suppliers used the sliding wire method, this method was selected for the study. The length of the wires is based on measurements that indicate that the section mainly had a larger carriage width than 3 m between the road markings. Based on this, two wires with a fixed length of 1,5 m each were used. This differs from the regulations in R211, where each wire is 1,0 m long [4]. Some variations between NPRA's fixed wire lengths and the variable wire length of the other suppliers will occur.

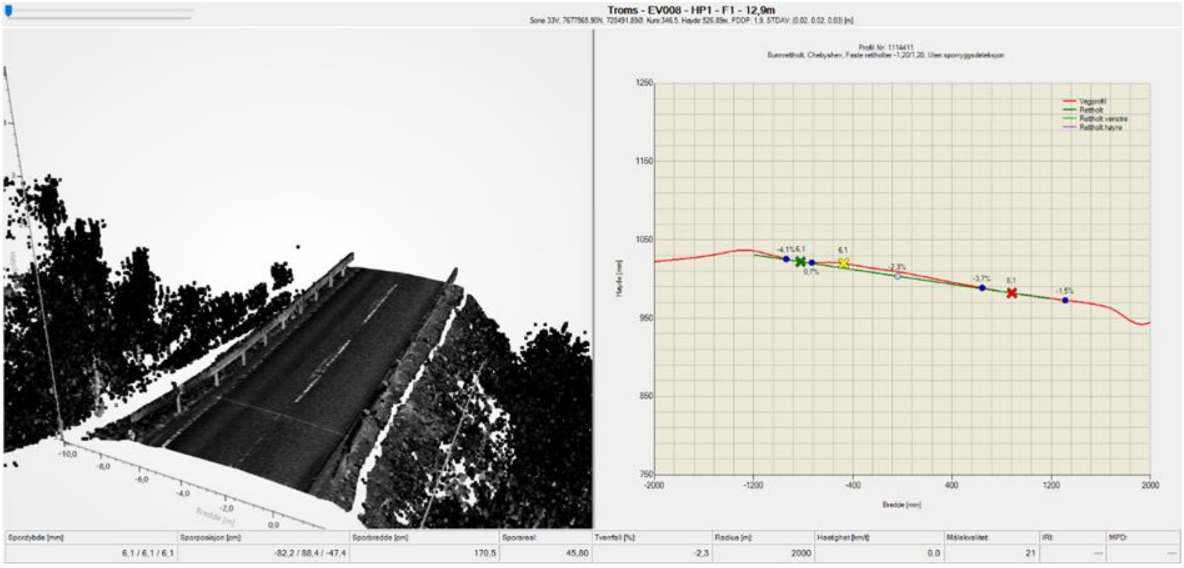
Pavement texture (MPD) and IRI is calculated using the ViaIRI+ texture laser. The ViaIRI+ texture laser has a resolution of 0,045 mm.

The roughness data (IRI) is classified according to international standards, mm/m. The data are presented as median values over 20 m. Roughness data are calculated by combining the height information from the texture scanner with the inertial motion unit. A profile is calculated each 0,25 m.

MPD and IRI are calculated for the right wheel path.

The data were interpreted using ViaPPS Desktop version 8.9.9.0, with 11 Chebyshev filters, and analysed with ViaPPS Analyse, version 4.7.9.1.

The report presents the NPRA data compared to each of the other supplier's data, for both 1- and 20-meter segments for each of the directions. Two sets of adjustment and/or scaling factor has been applied for each segment length and direction, one for the entire measured section and one for the selected section only. The values of both sections are shown to display the differences between them. For each comparison, a table shows the statistics for the selected section. Data in the tables are based on values that are adjusted for the selected section.



Troms - EV008 - HP1 - F1 - 12,9m

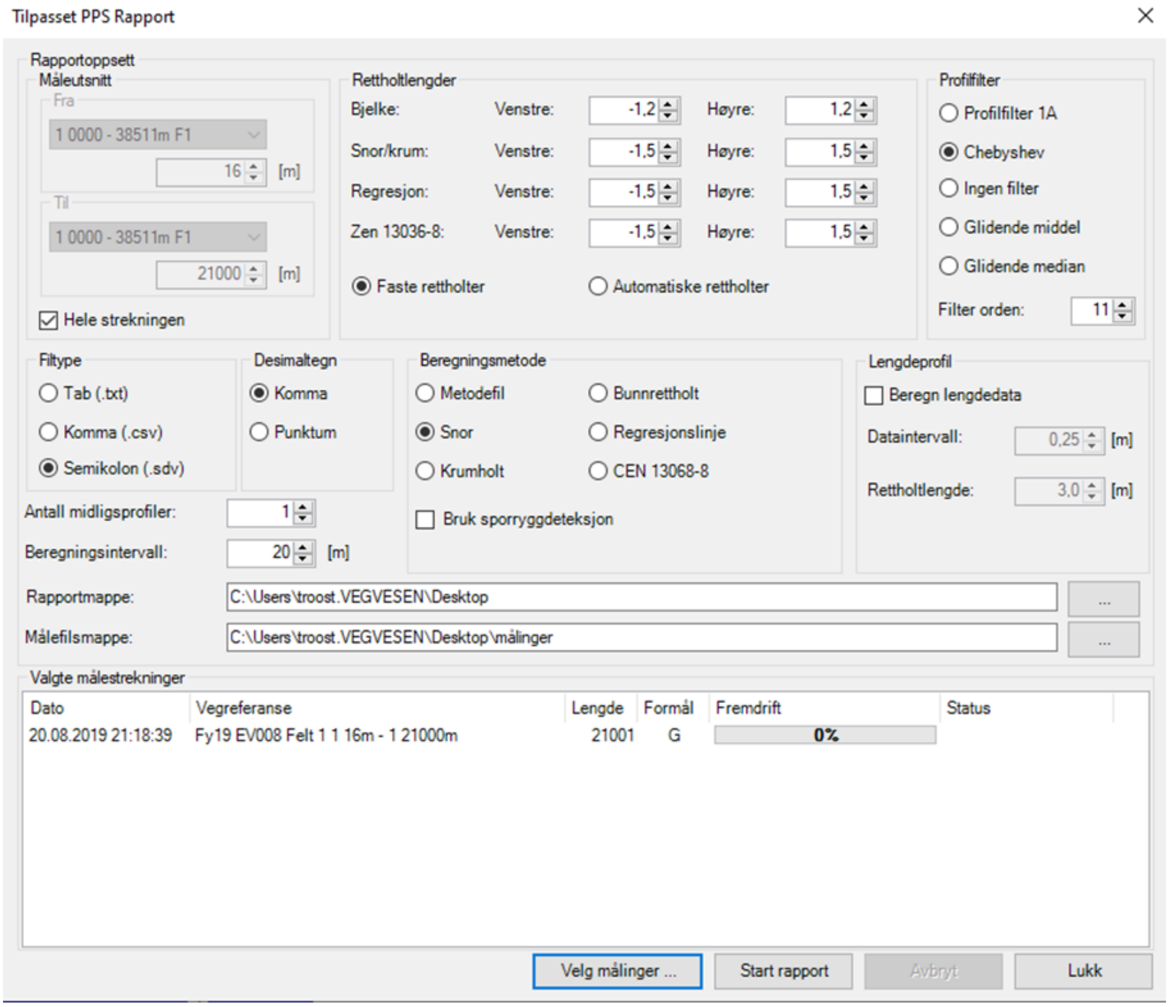
Sone 33V, 7677565.90N, 720491.850, Kurs 346.5, Høyde 526.89m, PDOP: 1.9, STDAV: (0.02, 0.02, 0.03) [m]

Profil Nr: 1114411

Bunnrettholt, Chebyshev, Faste rettholter -1,20/1,20, Uten sporryggdeteksjon

Spordybde [mm]:	Sporposisjon [cm]:	Sporbredde [cm]:	Sporareal:	Tverrfall [%]:	Radius [m]:	Hastighet [km/t]:	Målekvalitet:	IRI:	MPD:
6,1 / 6,1 / 6,1	-82,2 / 88,4 / -47,4	170,5	45,80	-2,3	2000	0,0	21	---	---

Figure 3: Point cloud and transversal profile from ViaPPS desktop



Tilpasset PPS Rapport

Rapportoppsett

Måleutsnitt

Fra

1 0000 - 38511m F1

16 [m]

Til

1 0000 - 38511m F1

21000 [m]

☑ Hele strekningen

Rettholtlengder

Bjelke:	Venstre:	-1,2	Høyre:	1,2
Snor/krum:	Venstre:	-1,5	Høyre:	1,5
Regresjon:	Venstre:	-1,5	Høyre:	1,5
Zen 13036-8:	Venstre:	-1,5	Høyre:	1,5

● Faste rettholter ○ Automatiske rettholter

Profilfilter

○ Profilfilter 1A
● Chebyshev
○ Ingen filter
○ Glidende middel
○ Glidende median

Filter orden: 11

Filtype

○ Tab (.txt)
○ Komma (.csv)
● Semikolon (.sdv)

Desimaltegn

● Komma
○ Punktum

Beregningsmetode

○ Metodefil ○ Bunnrettholt
● Snor ○ Regresjonslinje
○ Krumholt ○ CEN 13068-8

☐ Bruk sporryggdeteksjon

Lengdeprofil

☐ Beregn lengdedata

Dataintervall: 0,25 [m]

Rettholtlengde: 3,0 [m]

Antall midligsprofiler: 1

Beregningsintervall: 20 [m]

Rapportmappe: C:\Users\troost.VEGVESEN\Desktop

Målefilsmappe: C:\Users\troost.VEGVESEN\Desktop\målinger

Valgte målestrekninger

Dato	Vegreferanse	Lengde	Formål	Fremdrift	Status
20.08.2019 21:18:39	Fy19 EV008 Felt 1 1 16m - 1 21000m	21001	G	0%	

Figure 4: Calculation from ViaPPS Desktop

3 Roadscanners Oy

A laserscanner of the model Sick LMS500 was used for the measurements. The Sick LMS500 has an accuracy of less than 1 mm, with an average of 1 cm in cross sectional direction and 10 cm in longitudinal direction. Two laserscanners were used, to cover 360 degrees, and approximately 20-meter distance to the side.

Rutting was calculated using the sliding wire method, with a variable wire length based on the distance between the road markings.

Roughness was calculated using accelerometer based IRI, called “Response-Type road Roughness measurement system”, using the world bank’s classification of road roughness measurements device.

The crossfall was calculated from the point cloud data, using a linear regression line starting at the centreline and ending at the edge road marking.

The data were delivered in 1-, 10- and 20-meter segments. Only 1-meter and 20-meter segments were used for the analysis. Attachment 1 includes Roadscanzners’ data report.

The following data, also delivered by Roadscanners, were not used in this report:

- Ditch depth (presented in report 707 [7]).
- Side slope. Combining ditch depth and side slope gives valuable information for drainage evaluation.
- Verge, edge drop.

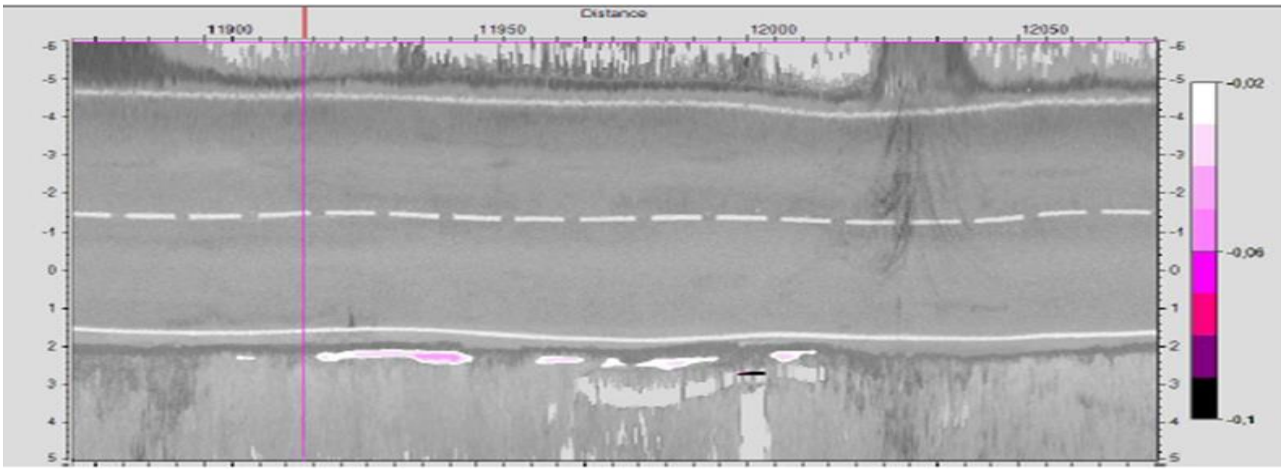


Figure 5: Example of verge, edge drops

- Homogenous surface sections.

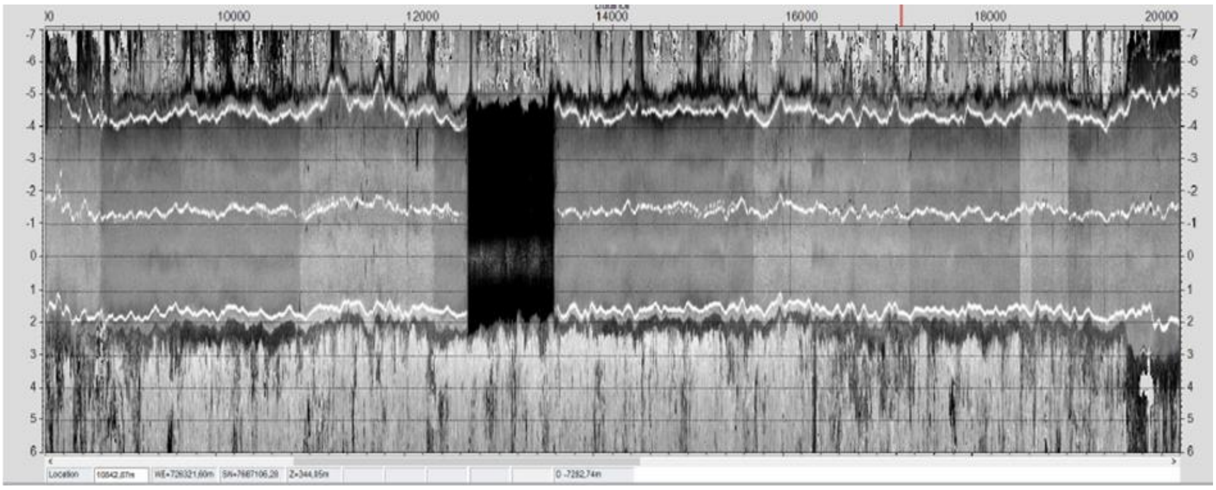


Figure 6: Example of the use of point cloud data from Roadscanners to see homogenous sections and patching

Figure 7: Roadscanners survey van [5]

3.1 20-meter segments

3.1.1 Direction 1 from the Finnish border – Skibotn

No adjustments to the starting point were made on the selected section. There is a good correlation with the NPRA data.

On the entire measured section, no adjustments were made either. The data show a good correlation at the beginning, but after a certain distance, the data are offset by -20 m compared to the NPRA data.

Table 1: Overview, 20-meter segments, direction 1, Roadscanners

NPRA wire 1,5m											
From	to	Rutting average	Rutting median	Rutting Std	Rutting 90%	Rutting 50%	IRI average	IRI median	IRI std	IRI 90 %	IRI 50 %
18600	19600	6,2	5,5	2,7	10,2	5,5	2,4	2,4	0,7	3,4	2,4
19600	20600	4,3	4,0	1,0	5,9	4,0	1,2	1,0	0,7	2,0	1,0
Roadscanners											
From	to	Rutting average	Rutting median	Rutting Std	Rutting 90%	Rutting 50%	IRI average	IRI median	IRI std	IRI 90 %	IRI 50 %
18600	19600	6,6	5,9	2,3	9,9	5,9	1,9	1,7	1,0	2,9	1,7
19600	20600	4,4	4,2	0,7	5,7	4,2	1,0	0,7	0,7	2,2	0,7

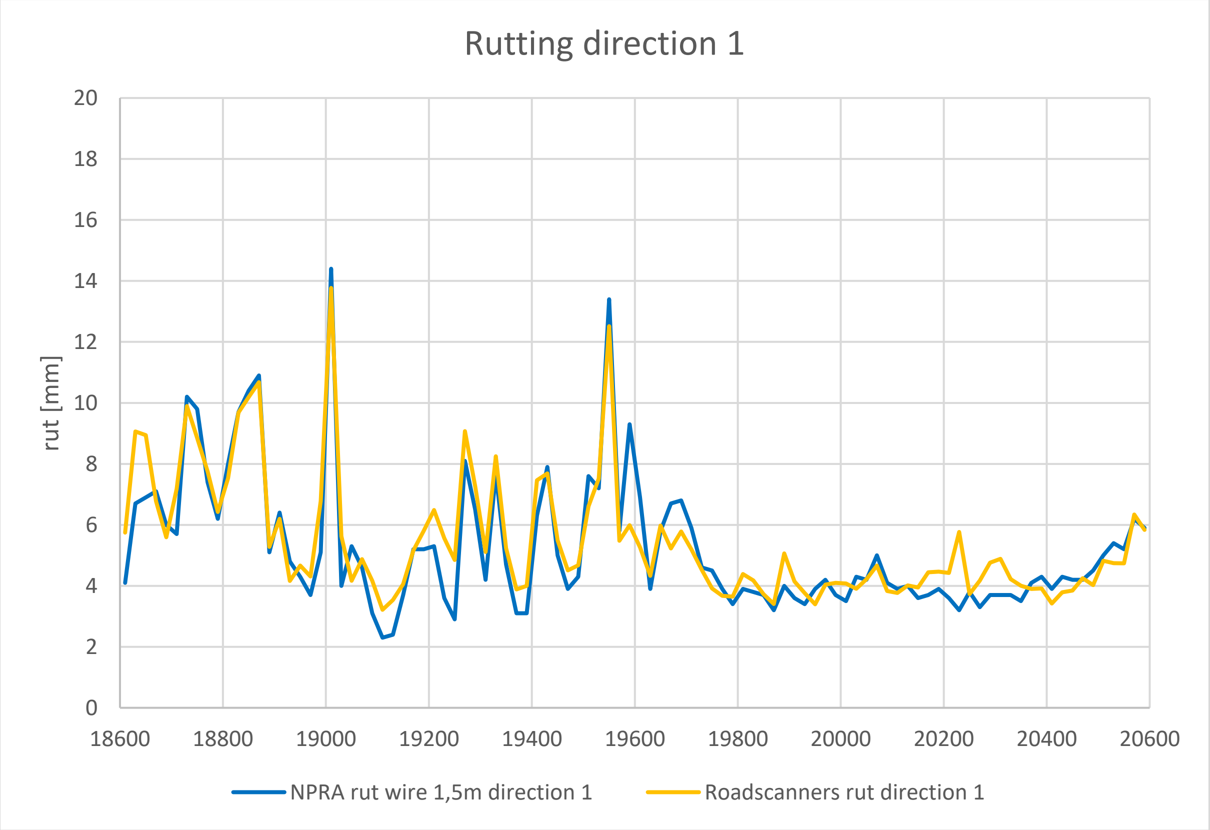


Figure 8: Rutting, 20-meter segments, direction 1, Roadscanners

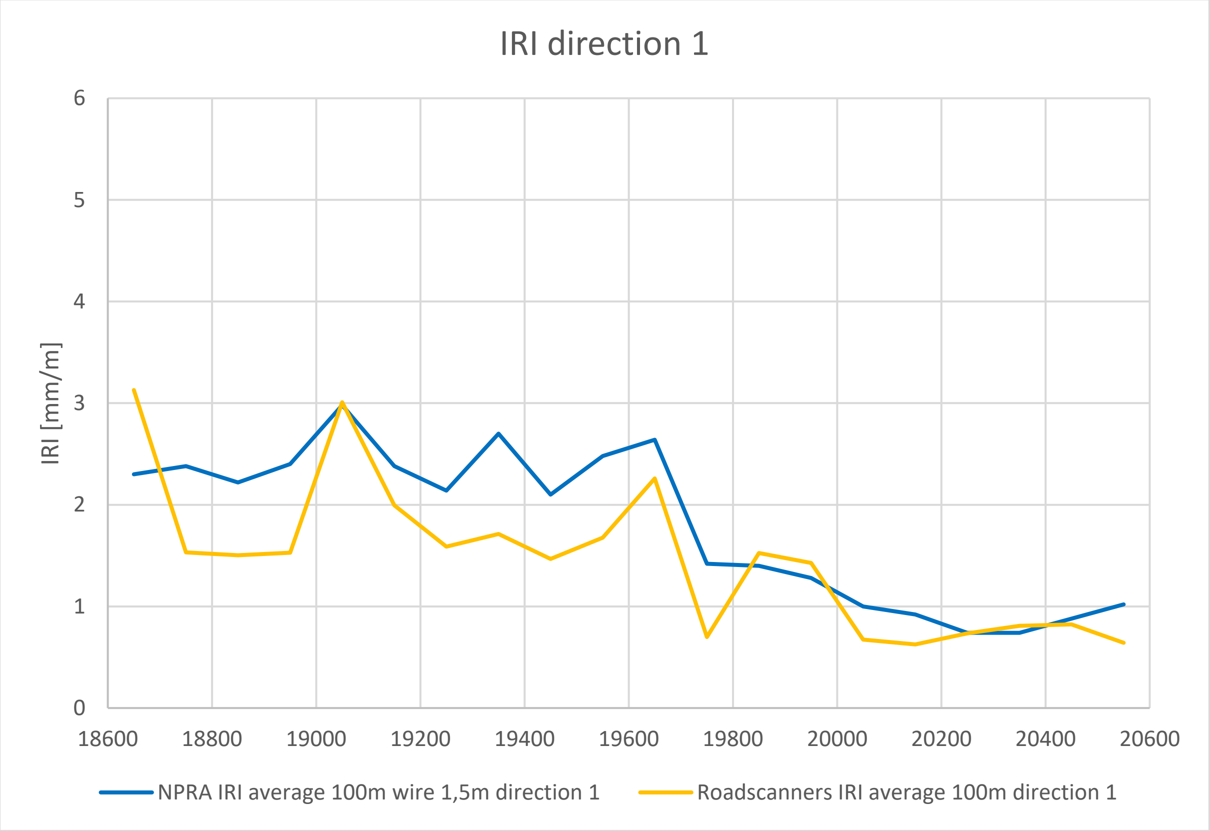


Figure 9: IRI, 20-meter segments, direction 1, Roadscanners

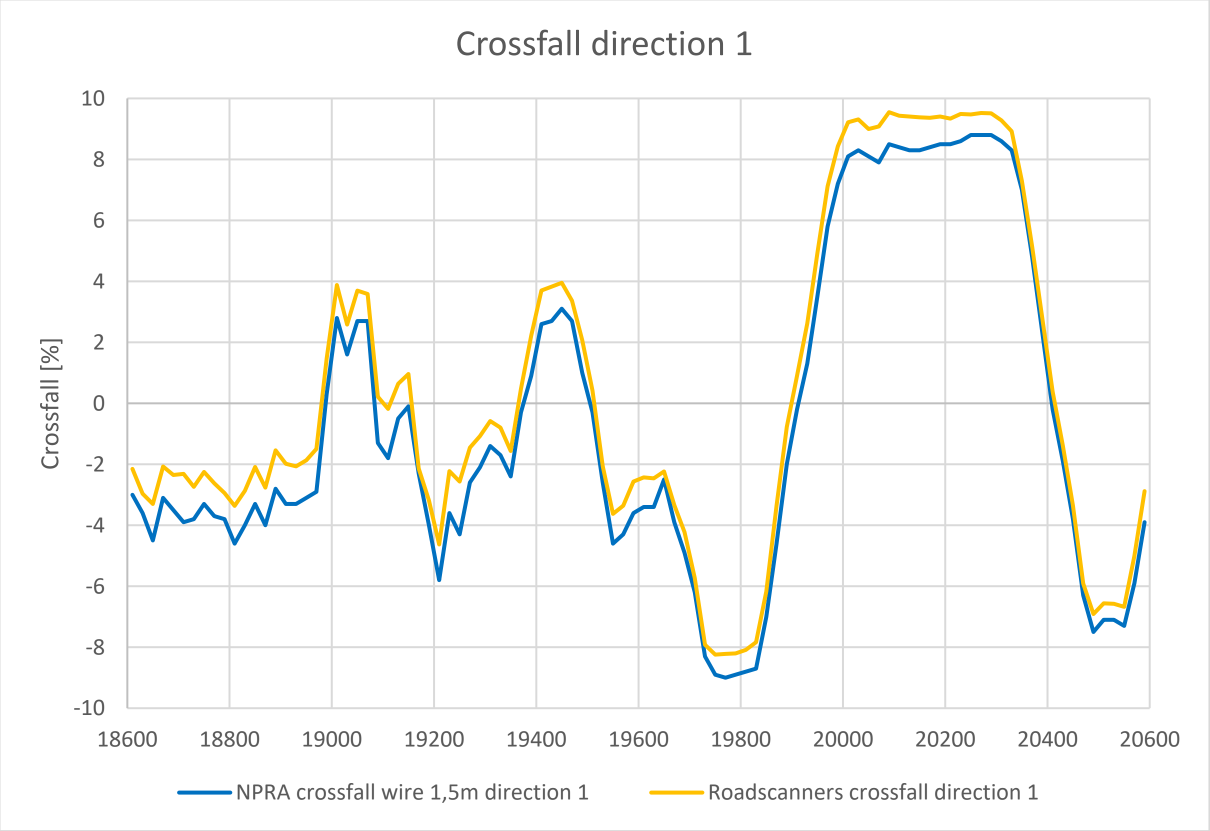


Figure 10: Crossfall, 20-meter segments, direction 1, Roadscanners

3.1.2 Direction 2 from Skibotn – Finnish border

The starting point for the selected section was not adjusted. There is a good correlation with the NPRA data.

The data of the entire measured area were adjusted by -20 m at the beginning. This gives a good correlation in the beginning, but the data are offset by -40 m by the end for the entire measured section.

Table 2: Overview, 20-meter segments, direction 2, Roadscanners

NPRA wire 1,5 m											
From	to	Rutting average	Rutting median	Rutting Std	Rutting 90 %	Rutting 50 %	IRI average	IRI median	IRI std	IRI 90 %	IRI 50 %
18600	19600	8,0	7,4	2,7	11,8	7,4	2,4	2,0	1,0	3,8	2,0
19600	20600	5,6	5,5	1,1	6,6	5,5	1,0	0,8	0,7	1,9	0,8
Roadscanners											
From	to	Rutting average	Rutting median	Rutting Std	Rutting 90 %	Rutting 50 %	IRI average	IRI median	IRI std	IRI 90 %	IRI 50 %
18600	19600	8,2	7,9	2,3	11,2	7,9	2,2	1,8	1,0	3,5	1,8
19600	20600	4,9	4,5	1,8	6,6	4,5	0,9	0,7	0,6	2,0	0,7

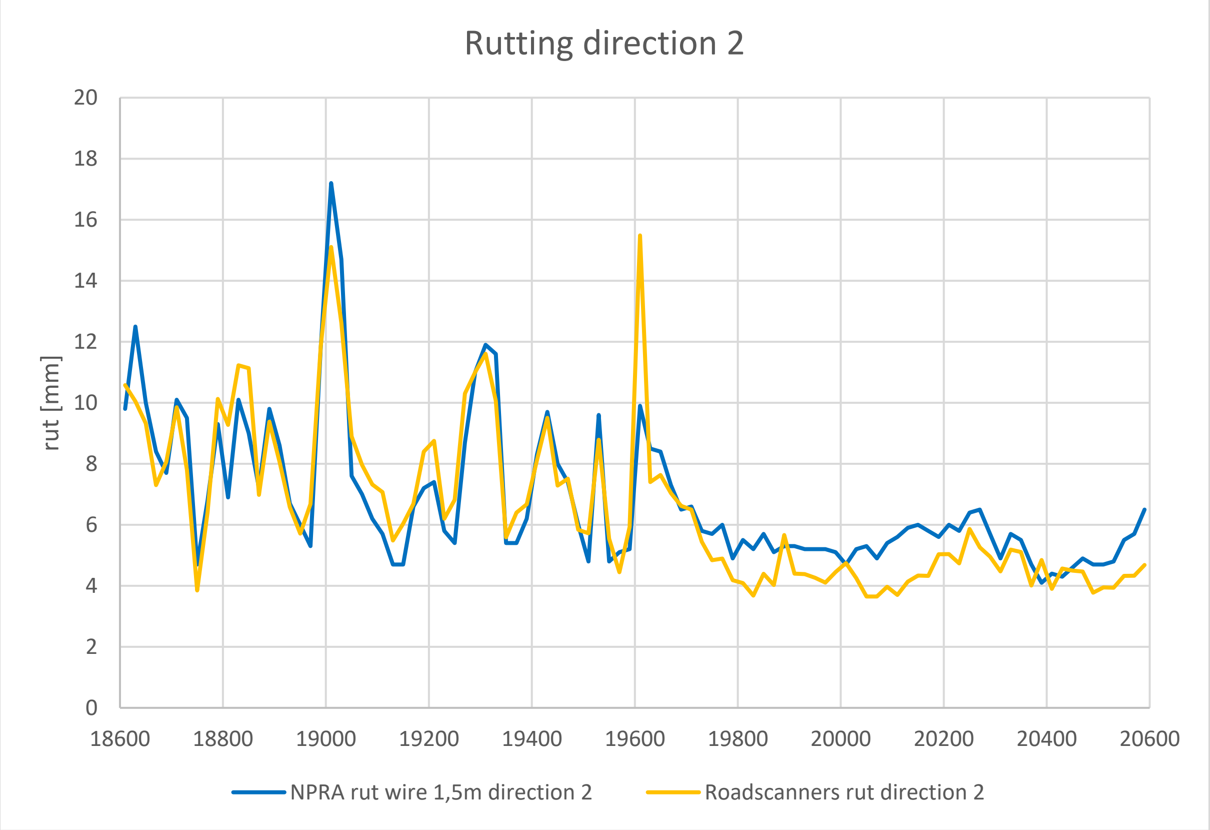


Figure 11: Rutting 20-meter segments direction 2 Roadscanners

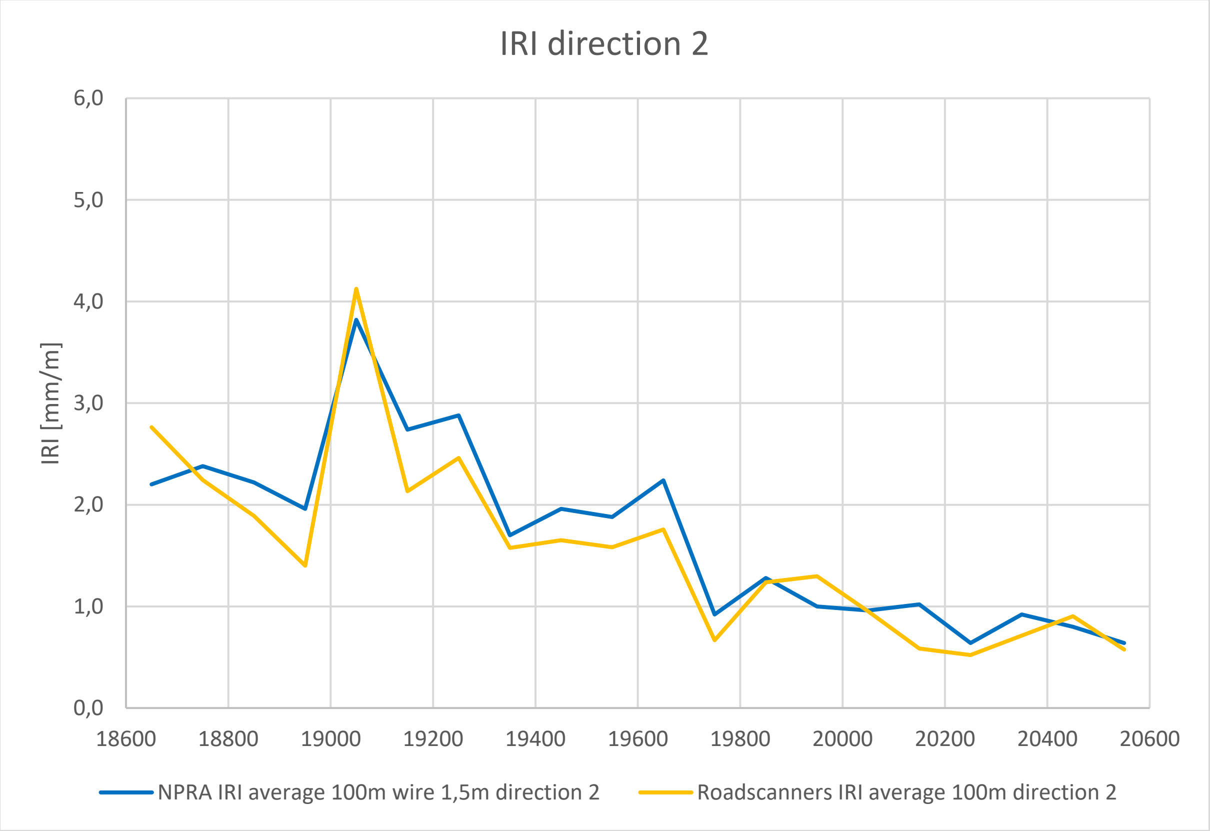


Figure 12: IRI 20-meter segments direction 2 Roadscanners

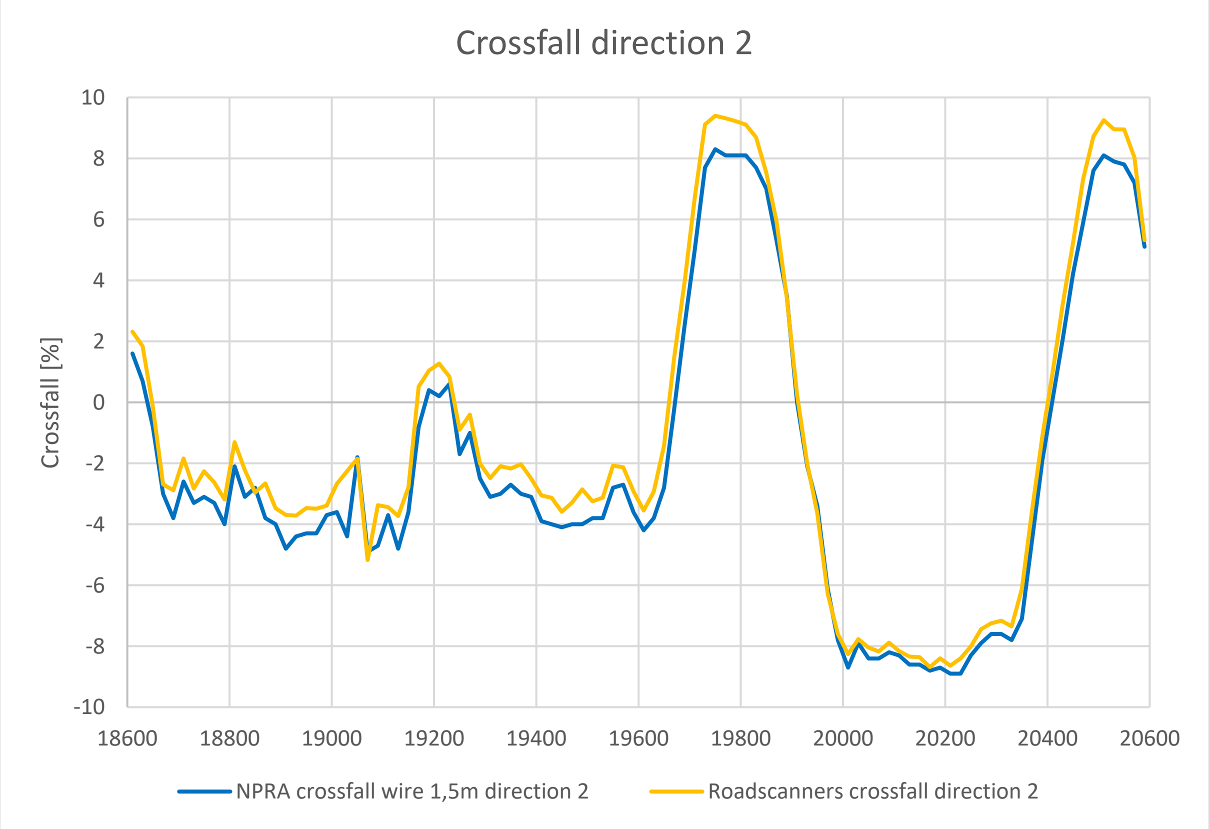


Figure 13: Crossfall 20-meter segments direction 2 Roadscanners

3.2 1-meter segments

3.2.1 Direction 1 from the Finnish border – Skibotn

The starting point for the selected section was adjusted by 2 m. This gives a good correlation to the NPRA data.

The starting point for the entire measured section was adjusted by 6 m. This gives a good correlation in the beginning, but there are some problems with the scaling over the middle part of the section.

Table 3: Overview, 1-meter segments, direction 1, Roadscanners

NPRA wire 1,5 m											
From	to	Rutting average	Rutting median	Rutting Std	Rutting 90 %	Rutting 50 %	IRI average	IRI median	IRI std	IRI 90 %	IRI 50 %
18600	19600	6,3	5,6	3,0	10,3	5,6	2,3	2,2	0,7	3,4	2,2
19600	20600	4,3	4,1	1,1	5,9	4,1	1,2	1,0	0,7	2,1	1
Roadscanners											
From	to	Rutting average	Rutting median	Rutting Std	Rutting 90 %	Rutting 50 %	IRI average	IRI median	IRI std	IRI 90 %	IRI 50 %
18600	19600	6,6	5,9	2,6	10,3	5,9	1,9	1,4	1,6	3,8	1,4
19600	20600	4,4	4,2	0,9	5,7	4,2	1,0	0,7	1,1	2,1	0,7

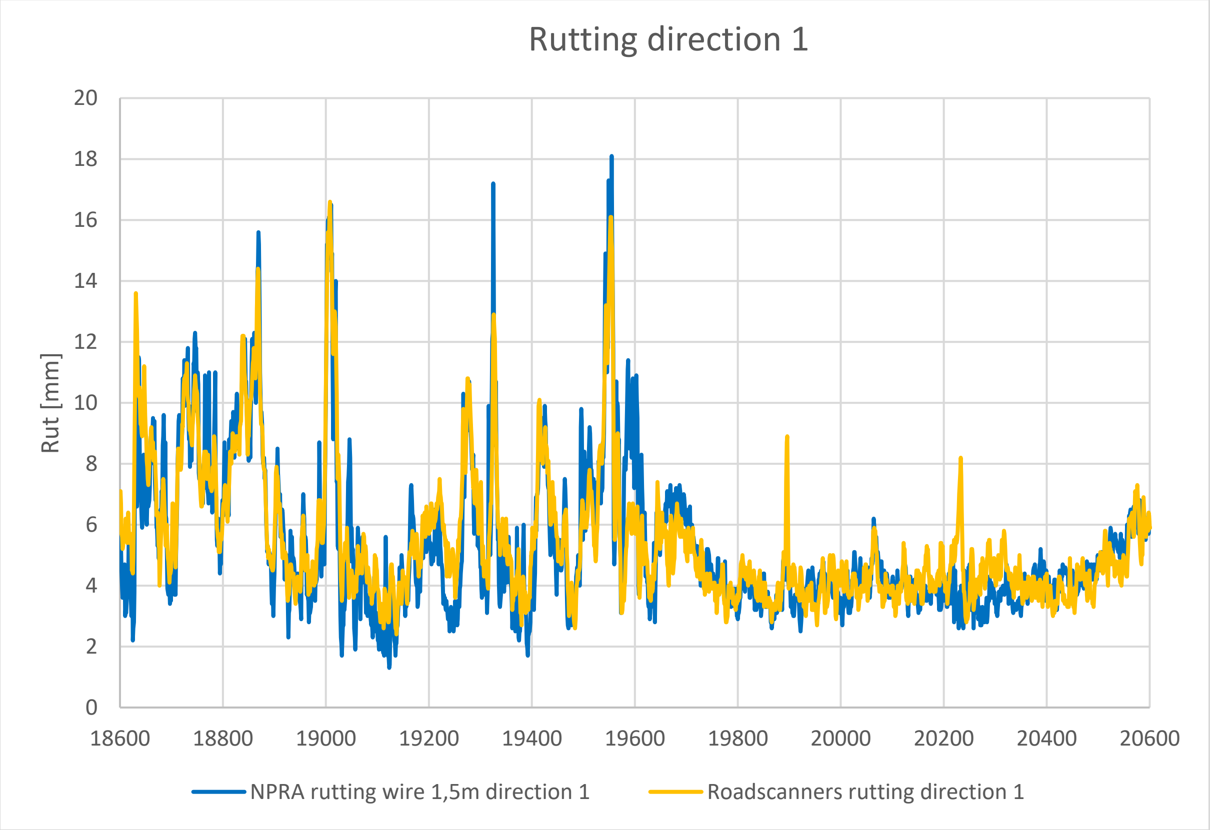


Figure 14: Rutting, 1-meter segments, direction 1, Roadscanners

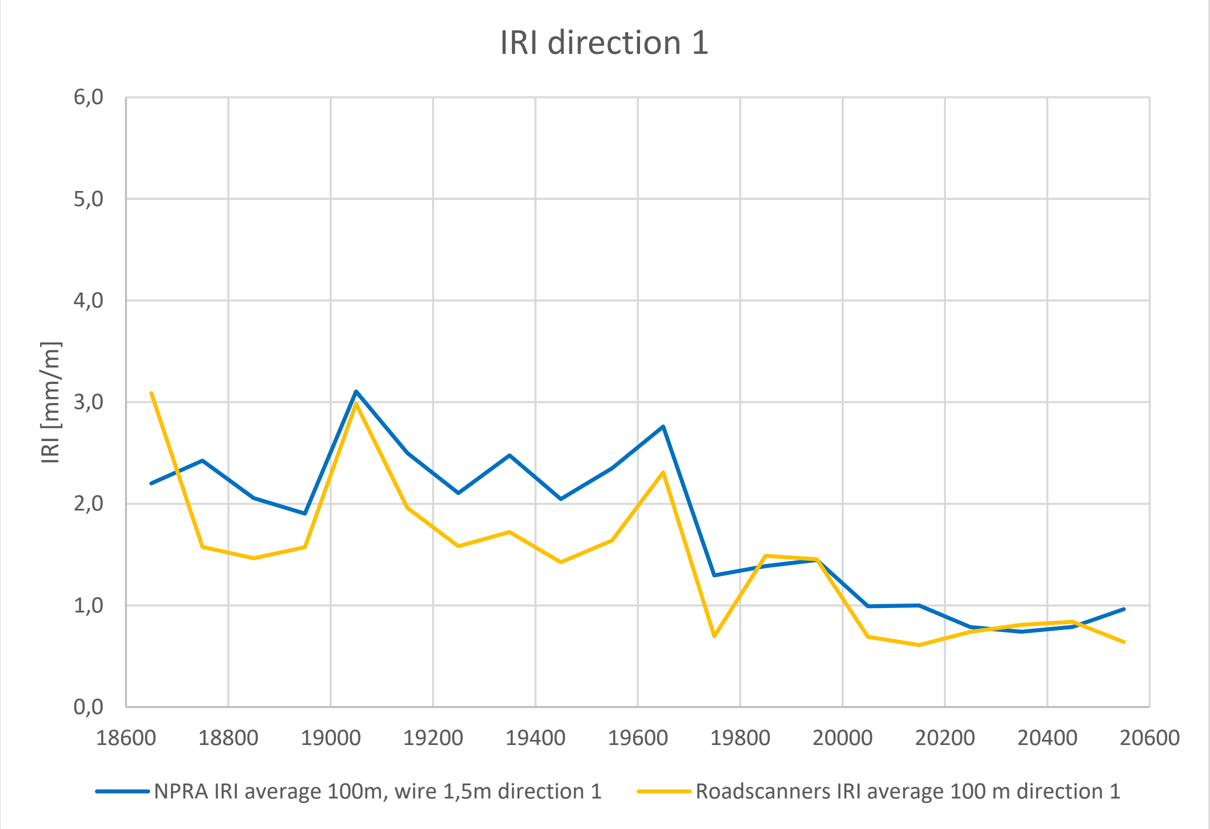


Figure 15: IRI, 1-meter segments, direction 1, Roadscanners

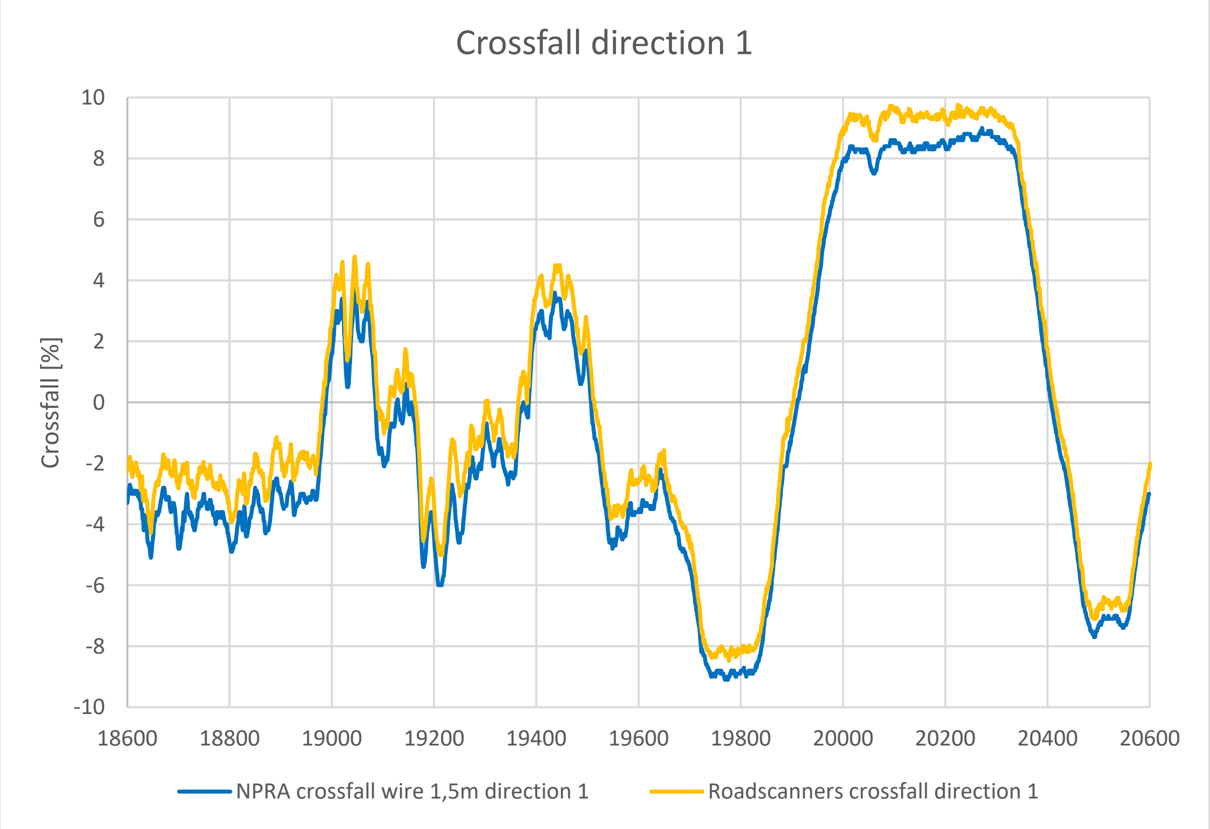


Figure 16: Crossfall, 1-meter segments, direction 1, Roadscanners

3.2.2 Direction 2 from Skibotn – Finnish border

The starting point of the selected section was adjusted by 4 m. This gives a good correlation between NPRA and Roadscanners data.

For the entire measured section, the starting point was adjusted by -14 m and a scaling of totally 32 m over the entire section was applied. Due to that, the data had a reasonably good correlation with the NPRA data over the entire measured section.

Table 4: Overview, 1-meter segments, direction 2, Roadscanners

NPRA wire 1,5 m											
From	to	Rutting average	Rutting median	Rutting Std	Rutting 90 %	Rutting 50 %	IRI average	IRI median	IRI std	IRI 90 %	IRI 50 %
18600	19600	8,1	7,4	3,1	12,0	7,4	2,4	2,2	0,9	3,7	2,2
19600	20600	5,8	5,5	2,2	6,7	5,5	1,0	0,8	0,6	1,5	0,8
Roadscanners											
From	to	Rutting average	Rutting median	Rutting Std	Rutting 90 %	Rutting 50 %	IRI average	IRI median	IRI std	IRI 90 %	IRI 50 %
18600	19600	8,2	7,7	2,6	11,8	7,7	2,2	1,7	1,8	4,5	1,7
19600	20600	4,9	4,5	2,1	6,6	4,5	0,9	0,6	0,9	1,8	0,6

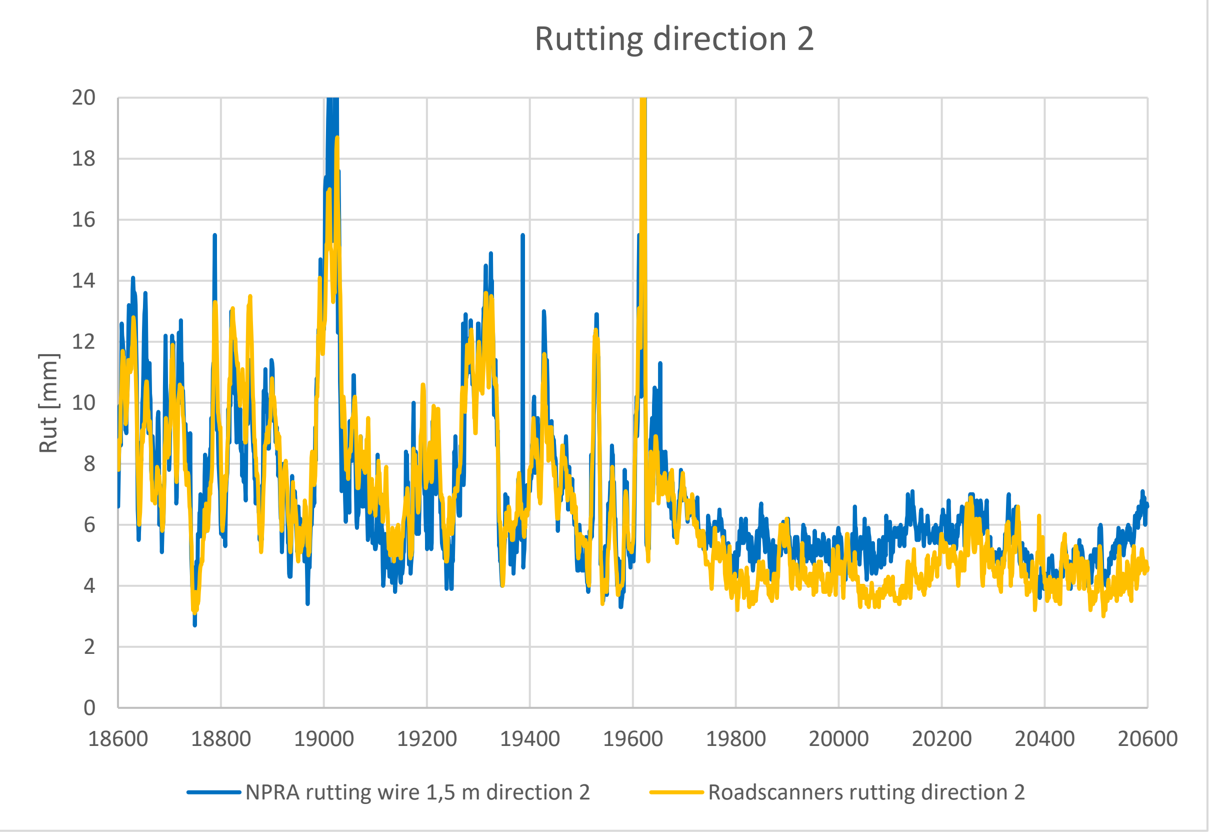


Figure 17: Rutting, 1-meter segments, direction 2, Roadscanners

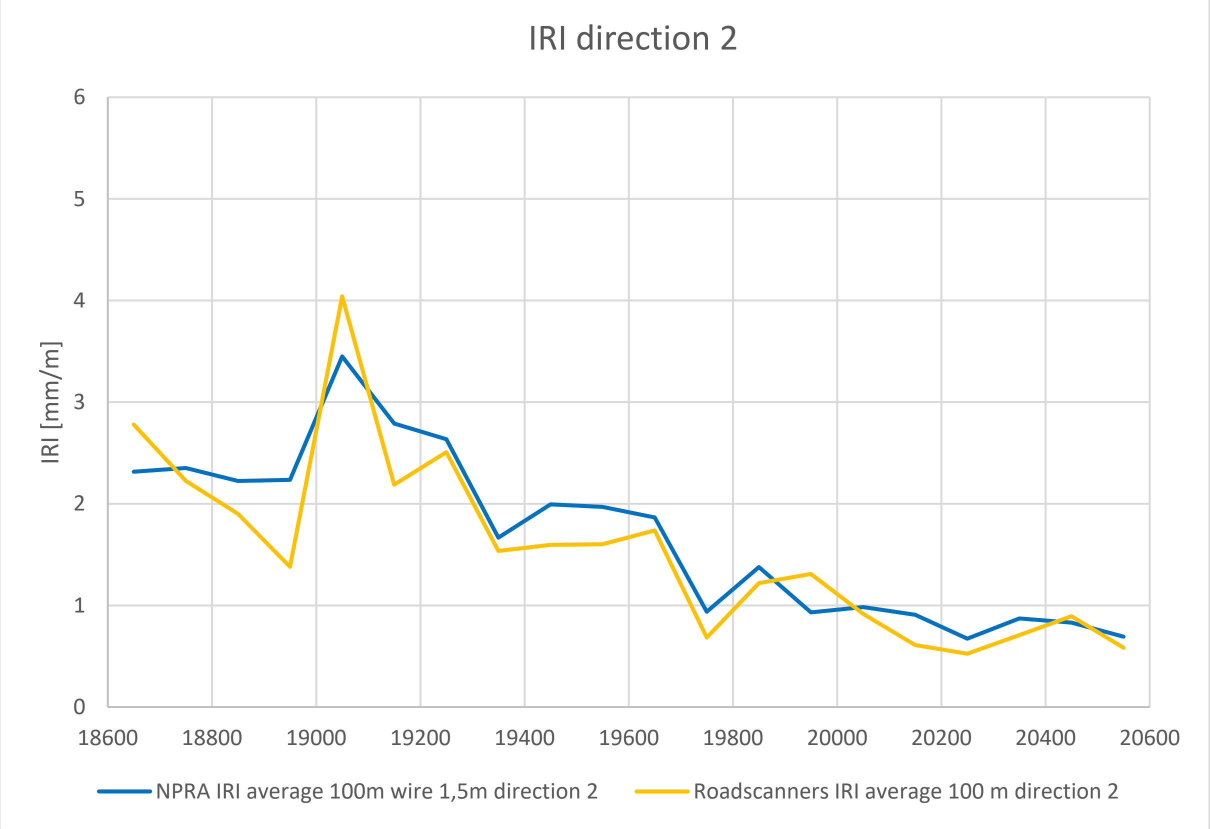


Figure 18: IRI, 1-meter segments, direction 2, Roadscanners

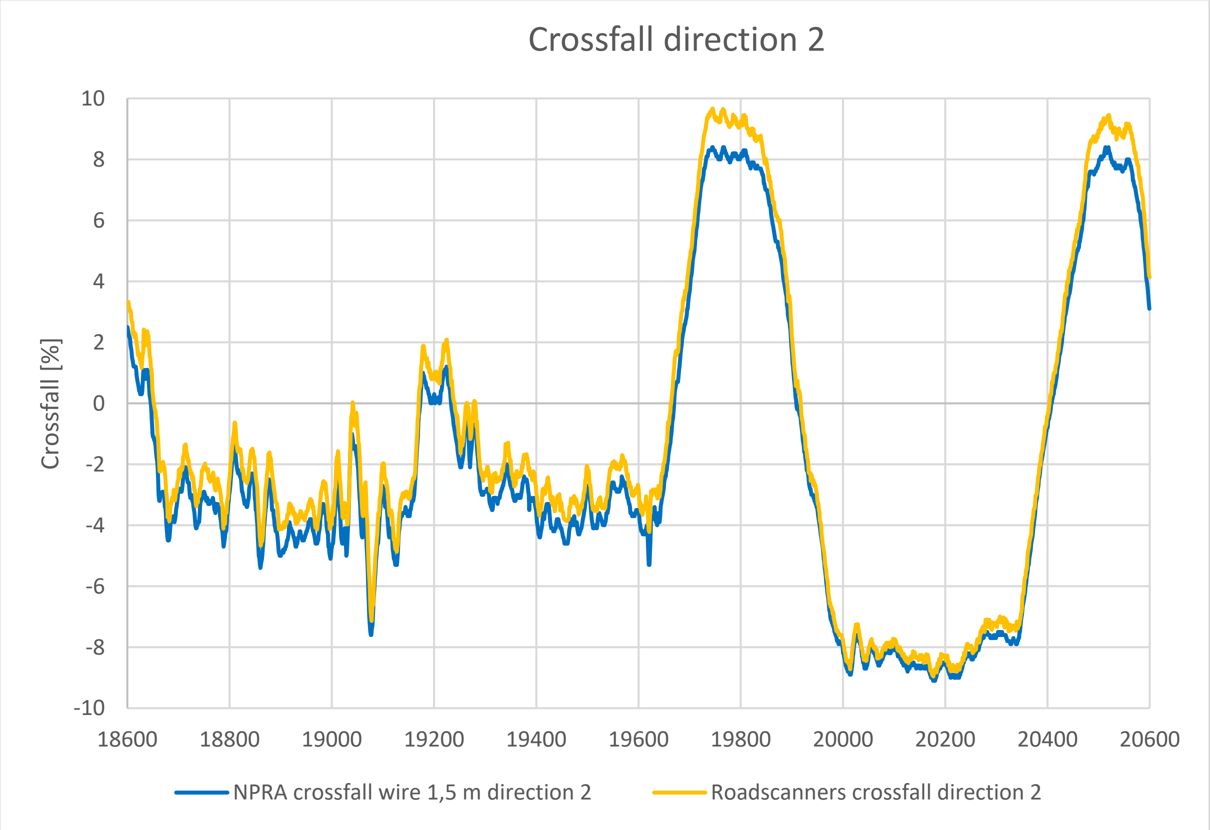


Figure 19: Crossfall, 1-meter segments, direction 2, Roadscanners

4 Ramboll

Ramboll used the Pavematrics system (Laser Crack measurement system - LCMS). The LCMS system uses two lasers to record a 4-meter lane width, with a transversal resolution of 1 mm (4096 points/profile) and profile spacing from 1-5 mm [7].

Rutting was calculated using the sliding wire method. The width of the wire is limited to the width of the road markings or to a maximum width of 3,2 m. Rutting is reported as maximum rut depth. It is not defined whether the values were reported as average values or median values, but according to TDOK 2014:0003, "Vägytemätning Mätstorheter" median values each 20 m are used [6].

Roughness was calculated using "Quarter car simulator", according to the "International world banks specification". IRI for the left and right wheel path is reported. However, the right wheel path is used in the analysis.

Crossfall was calculated from the transversal profile using regression slope, for each 10 cm. The Swedish standard TDOK 2014:0003 Vägytemâting Mätstorheter [6], chapter 2.6 states that the values should be averaged every meter. 20-meter segments are reported using median values, of the averaged meters.

MPD was calculated using the Swedish regulations. [referanse - TDOK 2014: 0003, Vägutemätning Mätstorheter, chapter 2.9.1.] Values were calculated for each 10 cm (Mean Segment Depth, MSD). The average values of these measurements (MSD) were used to calculate MPD for each meter. MPD for the right wheel path is used in the report.

The starting point and end point were calculated based on the GPS coordinates that were provided with the data. There are some discrepancies between calculated values compared to NPRA data. As a standard, all data were "calibrated" compared to NPRA data. The data for direction 2 are reversed, so the beginning of the data is at the Finnish border, and the end is at Skibotn. Ramboll's data report can be viewed in attachment 2.

Not all data presented by Ramboll are used in this report. In addition to the presented parameters, Ramboll's system also can detect:

- Surface damages (crack area, crack lengths)

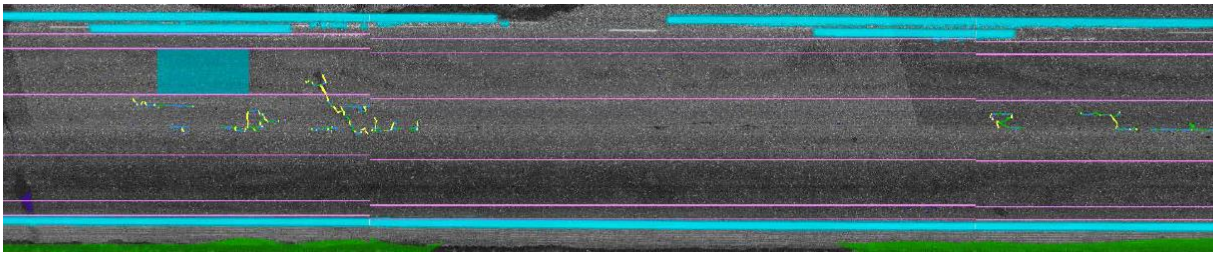


Figure 20: Crack images from LCMS system. Picture taken from Ramboll's report on E8 Borealis [8]

4.1 20-meter segment

4.1.1 Direction 1 from the Finnish border - Skibotn

The starting point was not adjusted in the selected section. The data correlate good for rutting, IRI and MPD, but the starting point for crossfall had to be adjusted by -20 m to get a good correlation with the NPRA data.

The starting point for the entire measured section was not adjusted for rutting, IRI, crossfall and MPD. The data correlate good in the beginning, but toward the end the data are offset by 20 m, compared with the NPRA data.

Table 5: Overview, 20-meter segments, direction 1, Ramboll

NPRA wire 1,5 m											
From	to	Rutting average	Rutting median	Rutting Std	Rutting 90 %	Rutting 50 %	IRI average	IRI median	IRI std	IRI 90 %	IRI 50 %
18600	19600	6,2	5,5	2,7	10,2	5,5	2,4	2,4	0,7	3,4	2,4
19600	20600	4,3	4,0	1,0	5,9	4,0	1,2	1,0	0,7	2,0	1,0
Ramboll											
From	to	Rutting average	Rutting median	Rutting Std	Rutting 90 %	Rutting 50 %	IRI average	IRI median	IRI std	IRI 90 %	IRI 50 %
18600	19600	5,3	4,9	2,0	8,1	4,9	2,3	2,1	0,8	3,6	2,1
19600	20600	4,4	4,3	0,7	5,3	4,3	1,0	0,8	0,8	1,9	0,8

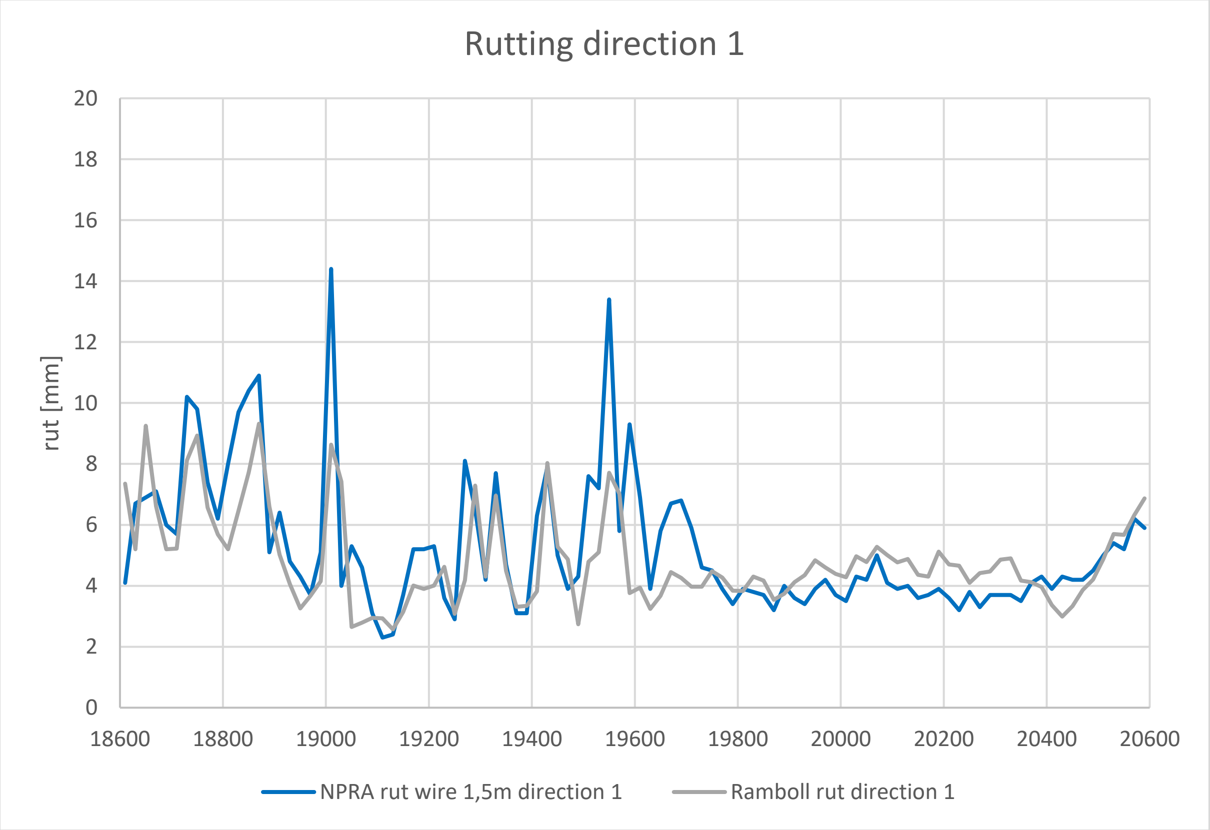


Figure 21: Rutting, 20-meter segments, direction 1, Ramboll

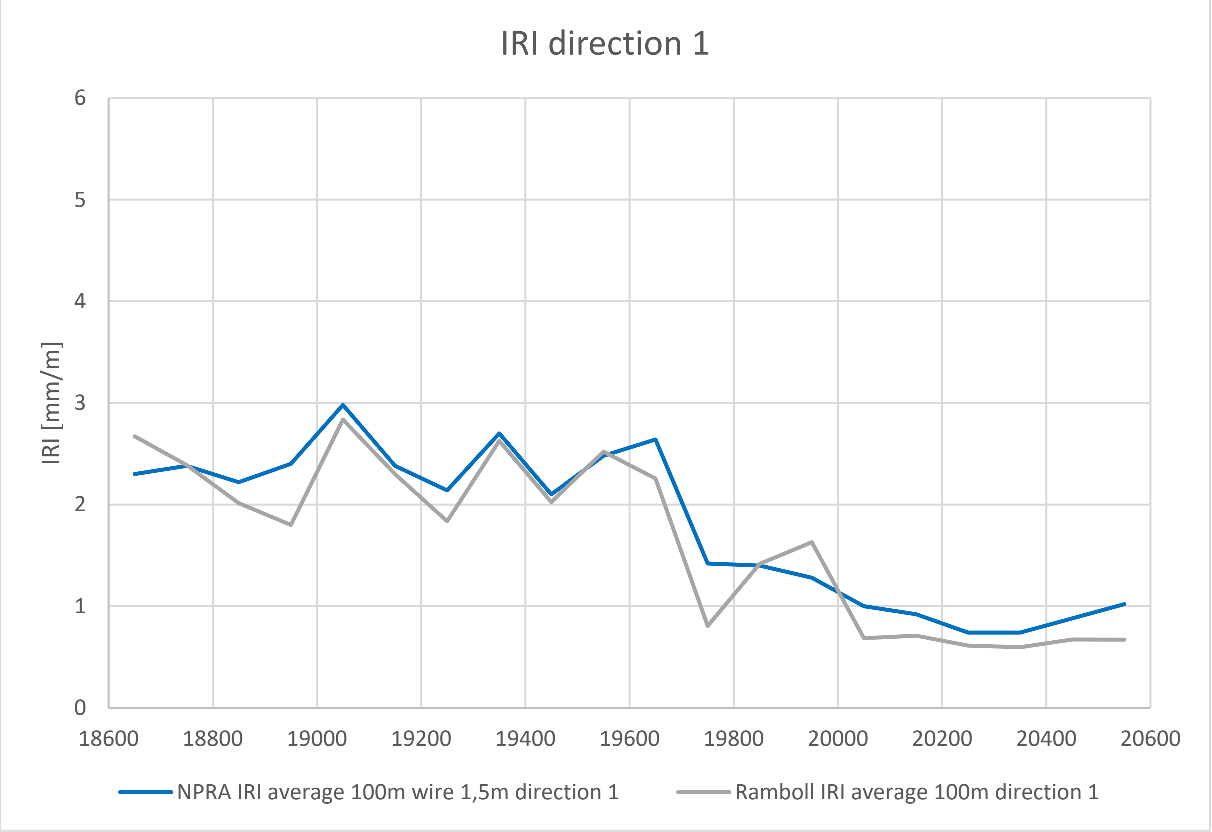


Figure 22: IRI, 20-meter segments, direction 1, Ramboll

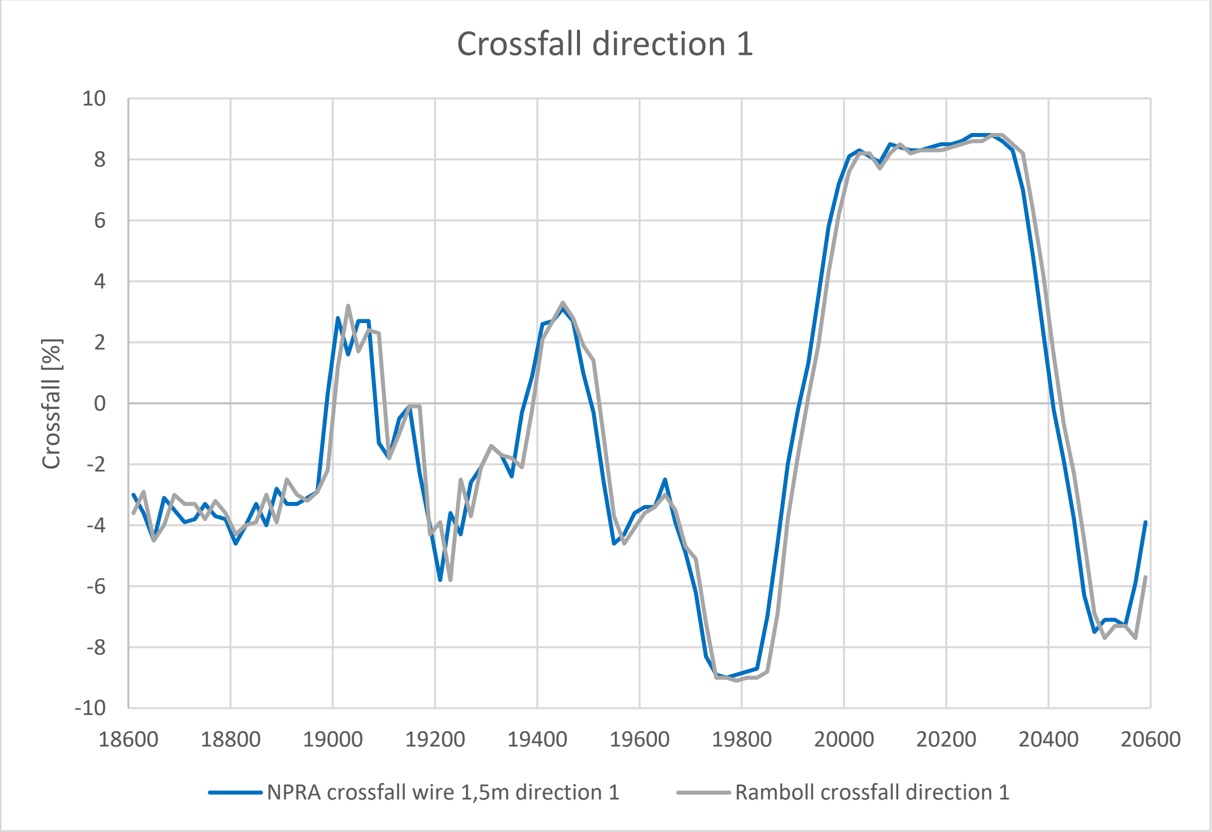


Figure 23: Crossfall, 20-meter segments, direction 1, Ramboll

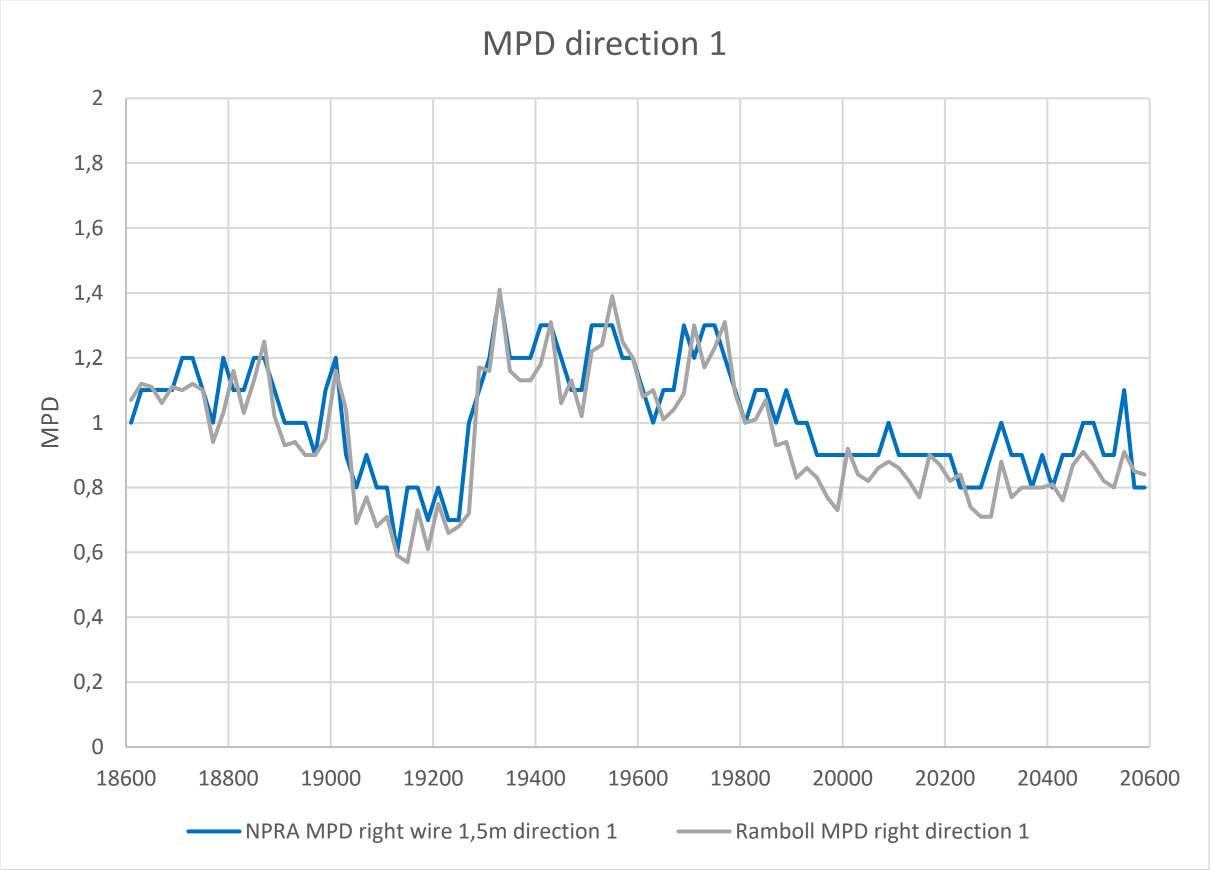


Figure 24: MPD, 20-meter segments, direction 1, Ramboll

4.1.2 Direction 2 from Skibotn – Finnish border

The starting point was adjusted by -60 m for the selected section. This gives a good correlation for rutting, IRI and MPD, but poor correlation for crossfall. The starting point for crossfall should be adjusted by -20 m to achieve a better correlation with the NPRA data.

For the entire measured section, a starting point adjustment of -40 m gives a good correlation in the beginning and middle section for rutting, IRI and MPD, but a poor correlation for crossfall. Towards the end of the test section Ramboll's data seem to be offset by -40 m, in comparison to the NPRA data.

Table 6: Overview, 20-meter segments, direction 2, Ramboll

NPRA wire 1,5 m											
From	to	Rutting average	Rutting median	Rutting Std	Rutting 90 %	Rutting 50 %	IRI average	IRI median	IRI Std	IRI 90 %	IRI 50 %
18600	19600	8,0	7,4	2,7	11,8	7,4	2,4	2,0	1,0	3,8	2,0
19600	20600	5,6	5,5	1,1	6,6	5,5	1,0	0,8	0,7	1,9	0,8
Ramboll											
From	to	Rutting average	Rutting median	Rutting Std	Rutting 90 %	Rutting 50 %	IRI average	IRI median	IRI Std	IRI 90 %	IRI 50 %
18600	19600	7,1	6,6	2,0	9,8	6,6	2,3	2,0	1,0	3,5	2,0
19600	20600	5,2	5,0	1,1	5,9	5,0	1,0	0,8	0,8	1,8	0,8

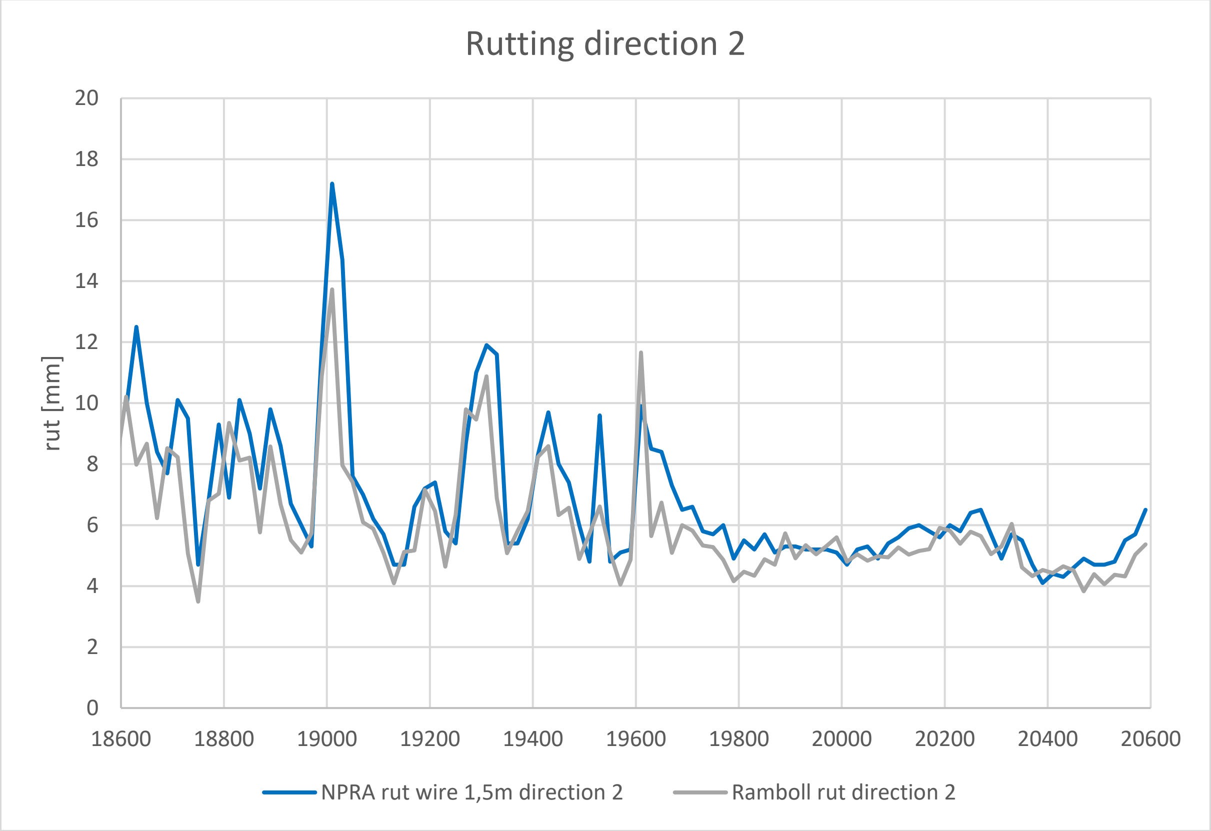


Figure 25: Rutting, 20-meter segments, direction 2, Ramboll

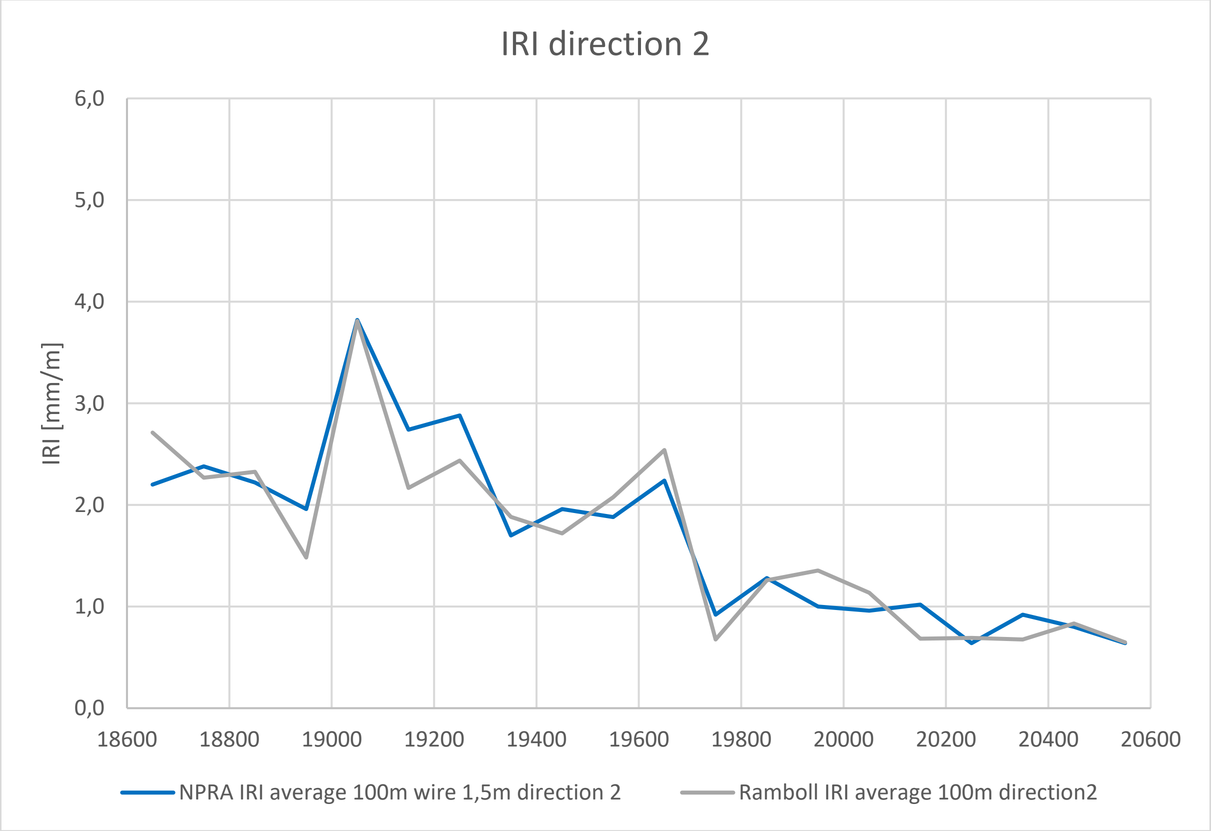


Figure 26: IRI, 20-meter segments, direction 2, Ramboll

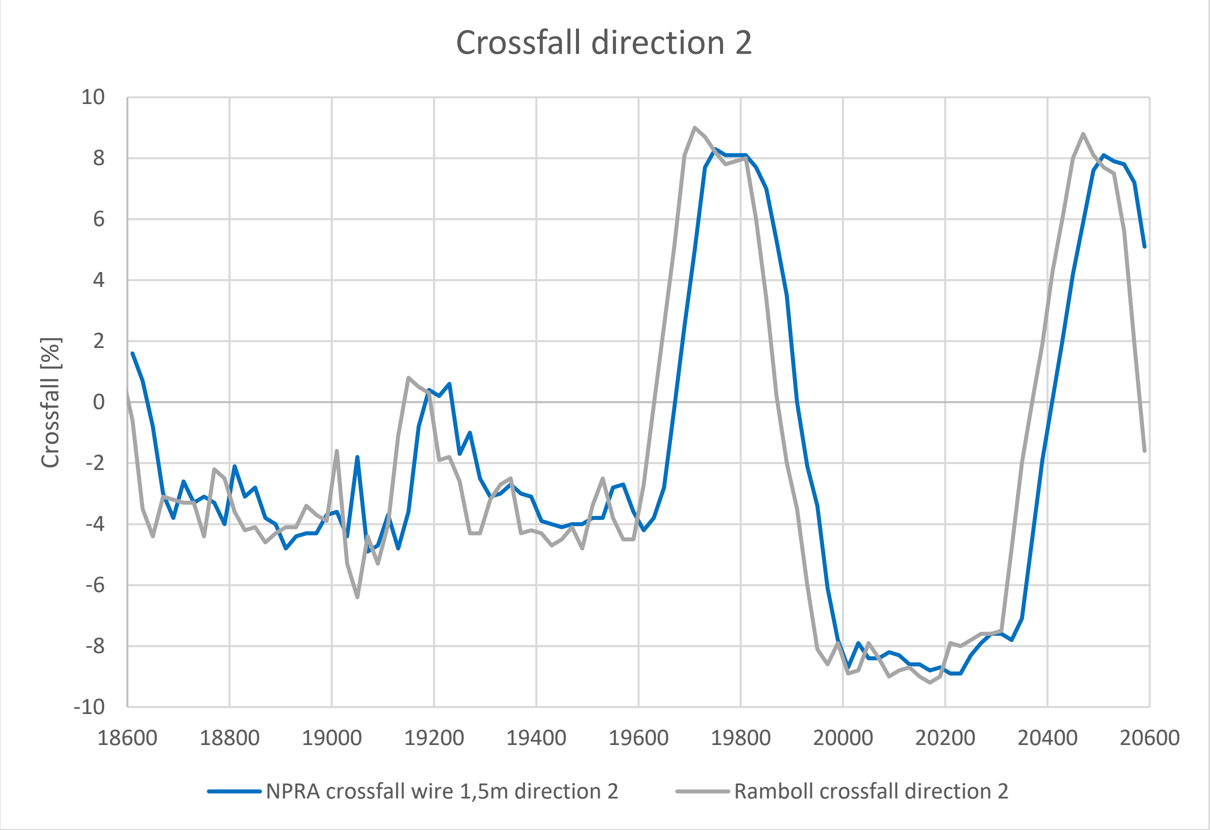


Figure 27: Crossfall, 20-meter segments, direction 2, Ramboll

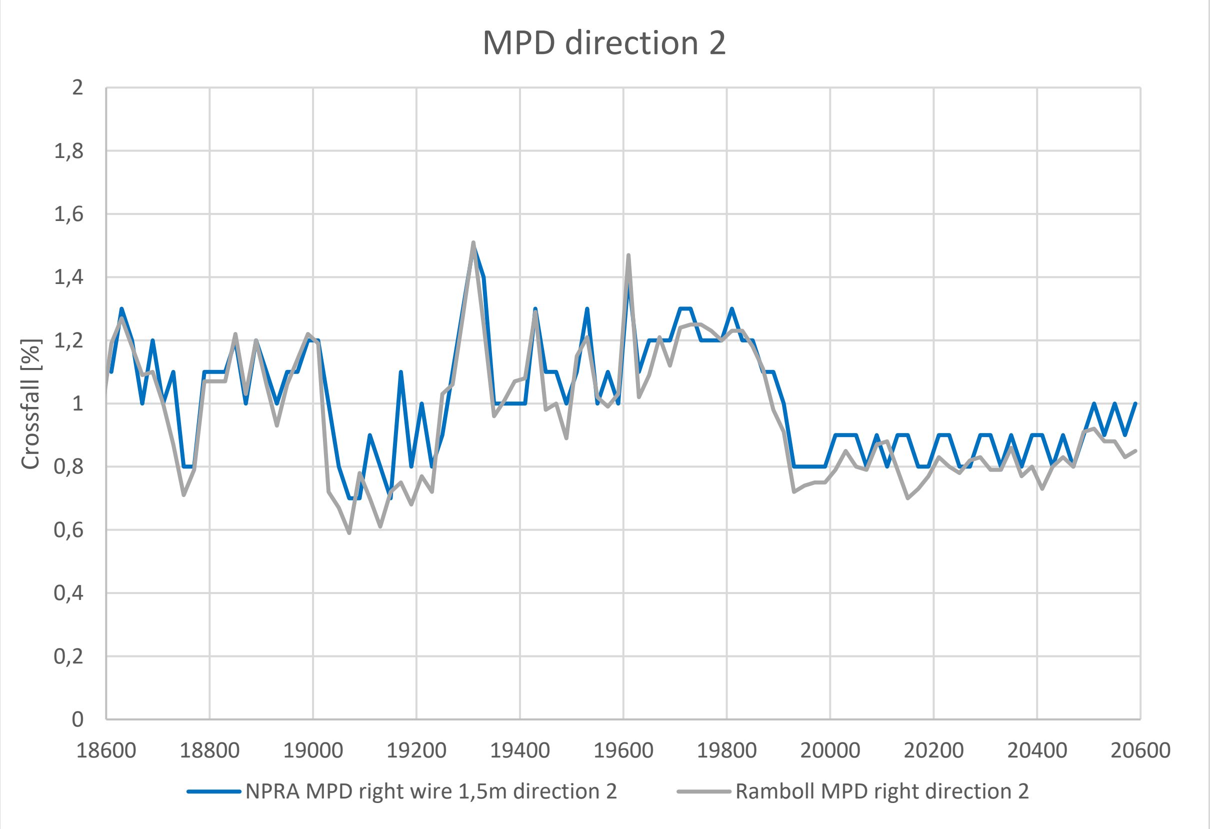


Figure 28: MPD, 20-meter segments, direction 2, Ramboll

4.2 1-meter segment

4.2.1 Direction 1 from the Finnish border - Skibotn

The starting point of the selected section was adjusted by -8 m. This gives a reasonably good correlation to the NPRA data.

For the entire measured section, the starting point was adjusted by 12 m. The data also needed to be scaled by -35 m over the entire length. This gives a good correlation with the NPRA data.

Table 7: Overview, 1-meter segments, direction 1, Ramboll

NPRA wire 1,5 m											
From	to	Rutting average	Rutting median	Rutting Std	Rutting 90 %	Rutting 50 %	IRI average	IRI median	IRI std	IRI 90 %	IRI 50 %
18600	19600	6,3	5,6	3,0	10,3	5,6	2,3	2,2	0,7	3,4	2,2
19600	20600	4,3	4,1	1,1	5,9	4,1	1,2	1,0	0,7	2,1	1
Ramboll											
From	to	Rutting average	Rutting median	Rutting Std	Rutting 90 %	Rutting 50 %	IRI average	IRI median	IRI std	IRI 90 %	IRI 50 %
18600	19600	5,2	4,7	2,4	8,7	4,7	2,3	1,8	1,8	4,4	1,8
19600	20600	4,4	4,4	0,9	5,4	4,4	1,0	0,7	1,1	1,8	0,7

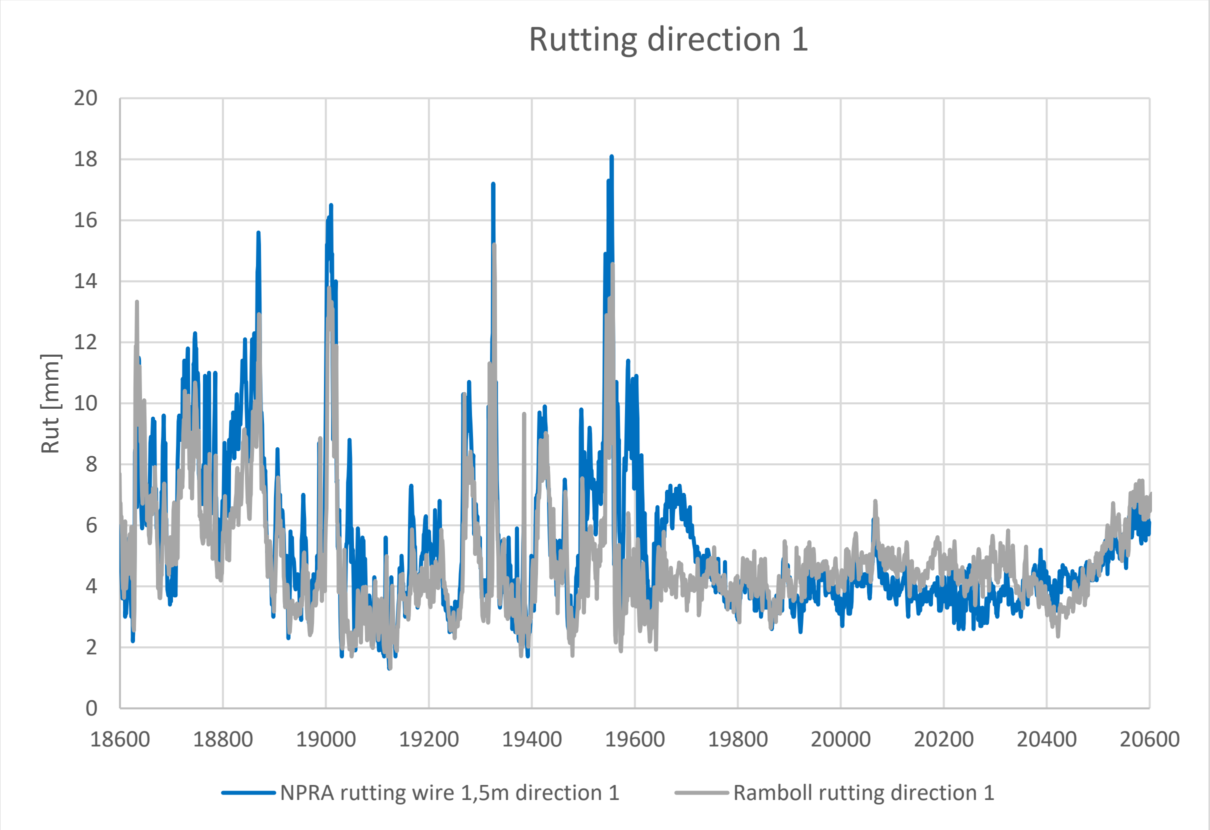


Figure 29: Rutting, 1-meter segments, direction 1, Ramboll

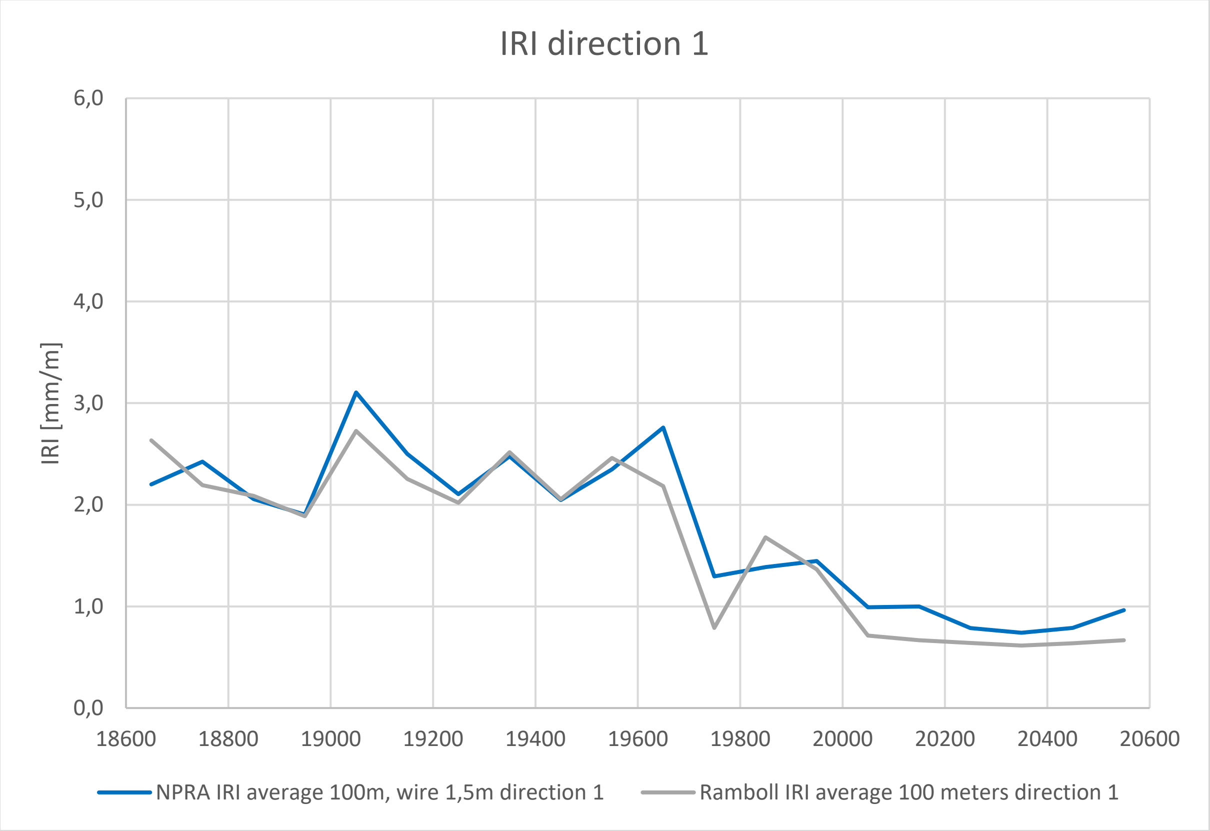


Figure 30: IRI, 1-meter segments, direction 1, Ramboll

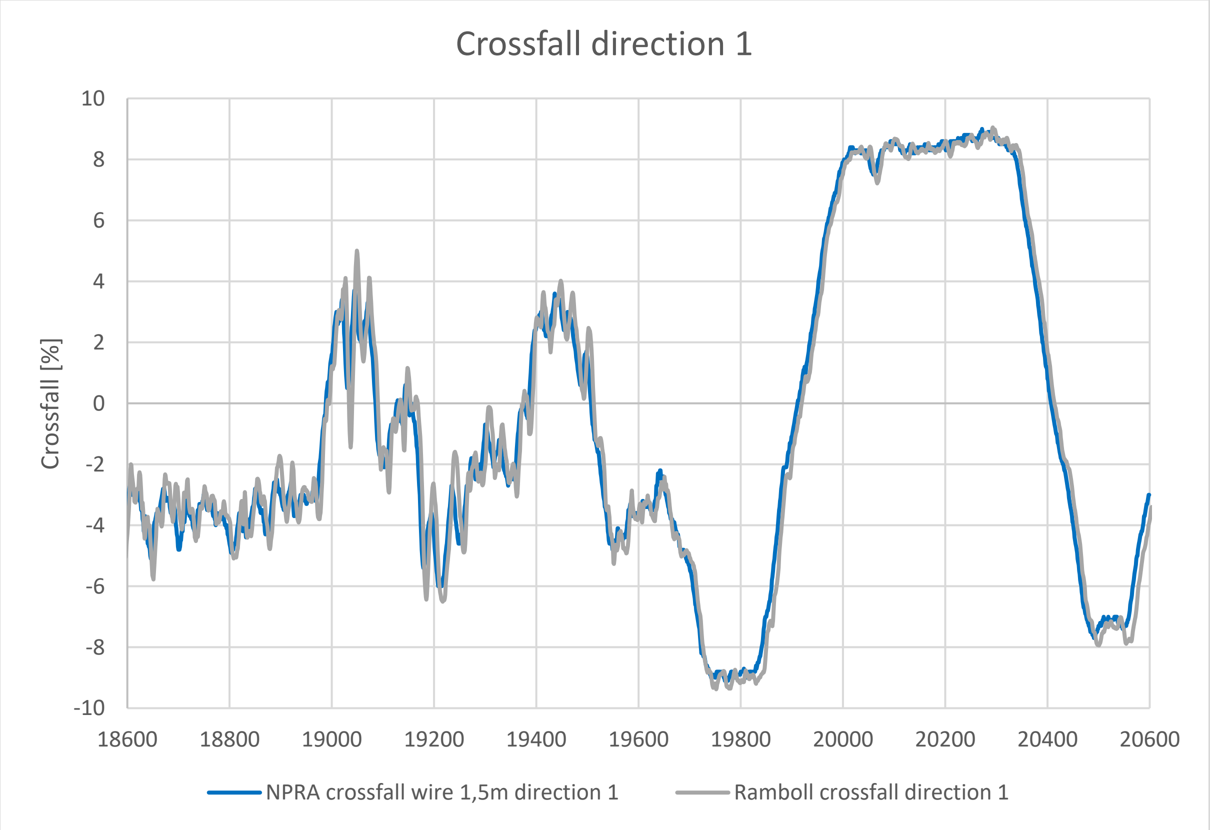


Figure 31: Crossfall, 1-meter segments, direction 1, Ramboll

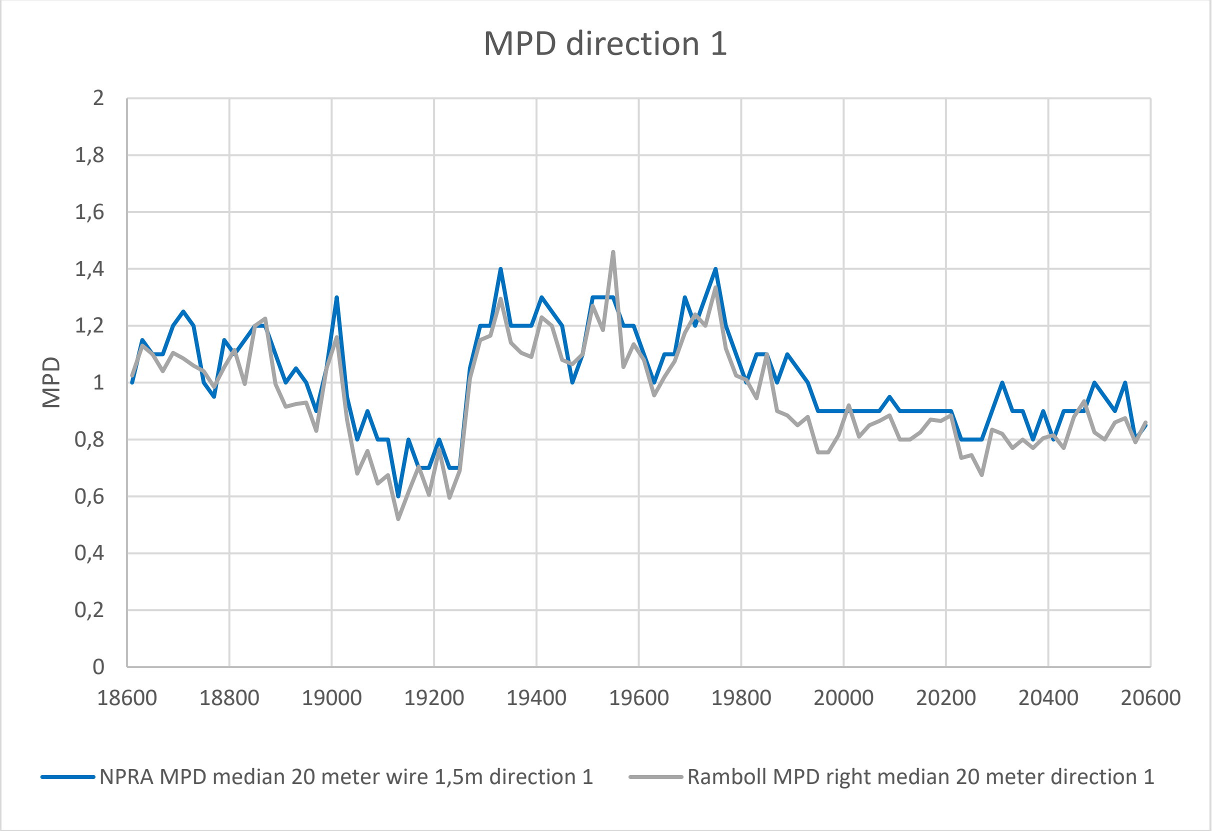


Figure 32: MPD, 1-meter segments, direction 1, Ramboll

4.2.2 Direction 2 from Skibotn – Finnish border

The starting point of the selected section was adjusted by -32 m. In addition, a scaling of -3 m was applied. This gives a good correlation to the NPRA data for rutting, IRI, and MPD, however, not for crossfall. Crossfall values show the best correlation to the NPRA data without adjustments.

The starting point of the entire measured section was adjusted by -16 m. I addition, a scaling of -14 m was applied. This gives a good correlation to the NPRA data at the beginning and the end for rutting, IRI and MPD, but in the middle the correlation is not so good. This adjustment gives a poor correlation for crossfall at the beginning and the middle section, but a good correlation at the end. To get a good correlation for crossfall the starting point should be adjusted by 12 m, and a scaling factor of -14 m should be applied. This would give a good correlation at the beginning and the middle section, but the data would be offset at the end by 25 m.

Table 8: Overview, 1-meter segments, direction 2, Ramboll

NPRA wire 1,5 m											
From	to	Rutting average	Rutting median	Rutting Std	Rutting 90 %	Rutting 50 %	IRI average	IRI median	IRI std	IRI 90 %	IRI 50 %
18600	19600	8,1	7,4	3,1	12,0	7,4	2,4	2,2	0,9	3,7	2,2
19600	20600	5,8	5,5	2,2	6,7	5,5	1,0	0,8	0,6	1,5	0,8
Ramboll											
From	to	Rutting average	Rutting median	Rutting Std	Rutting 90 %	Rutting 50 %	IRI average	IRI median	IRI std	IRI 90 %	IRI 50 %
18600	19600	7,1	6,7	2,5	10,5	6,7	2,3	1,8	2,0	4,7	1,8
19600	20600	5,2	5,0	1,4	6,1	5,0	1,1	0,7	1,2	2,1	0,7

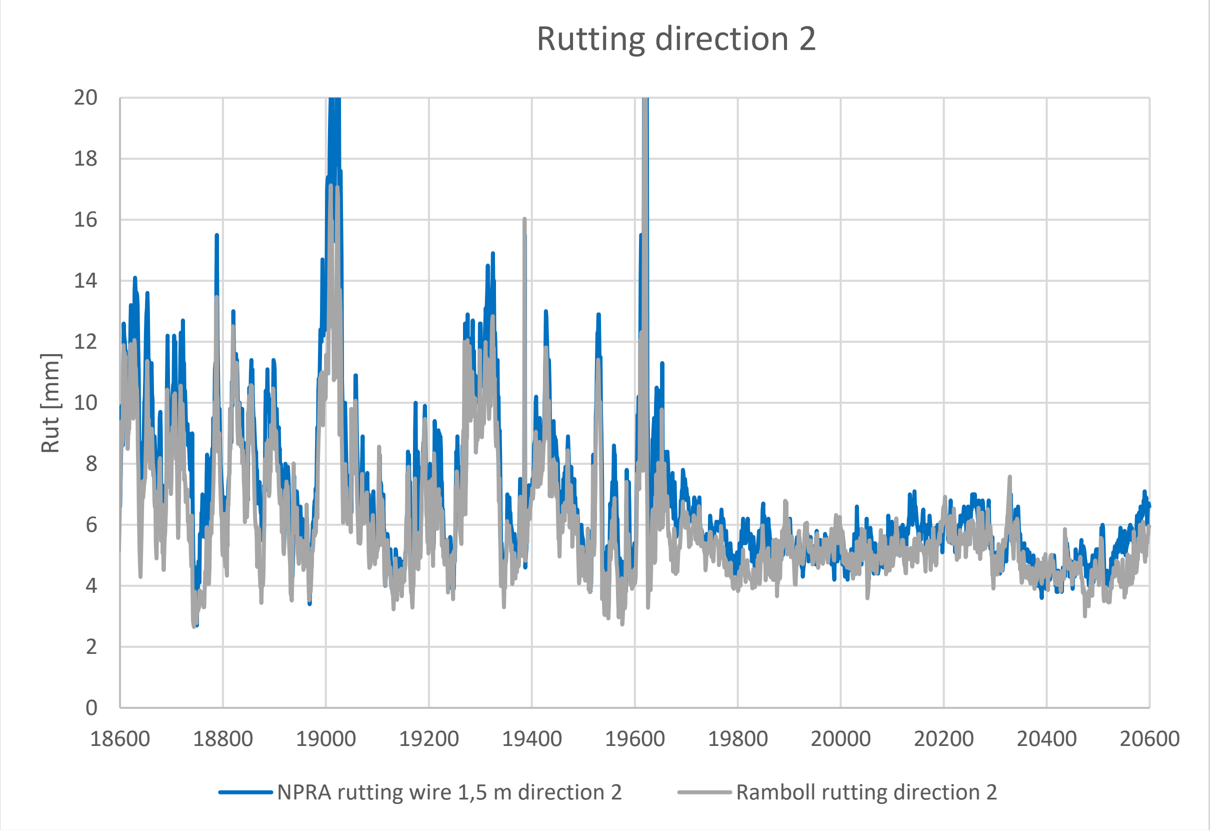


Figure 33: Rutting, 1-meter segments, direction 2, Ramboll

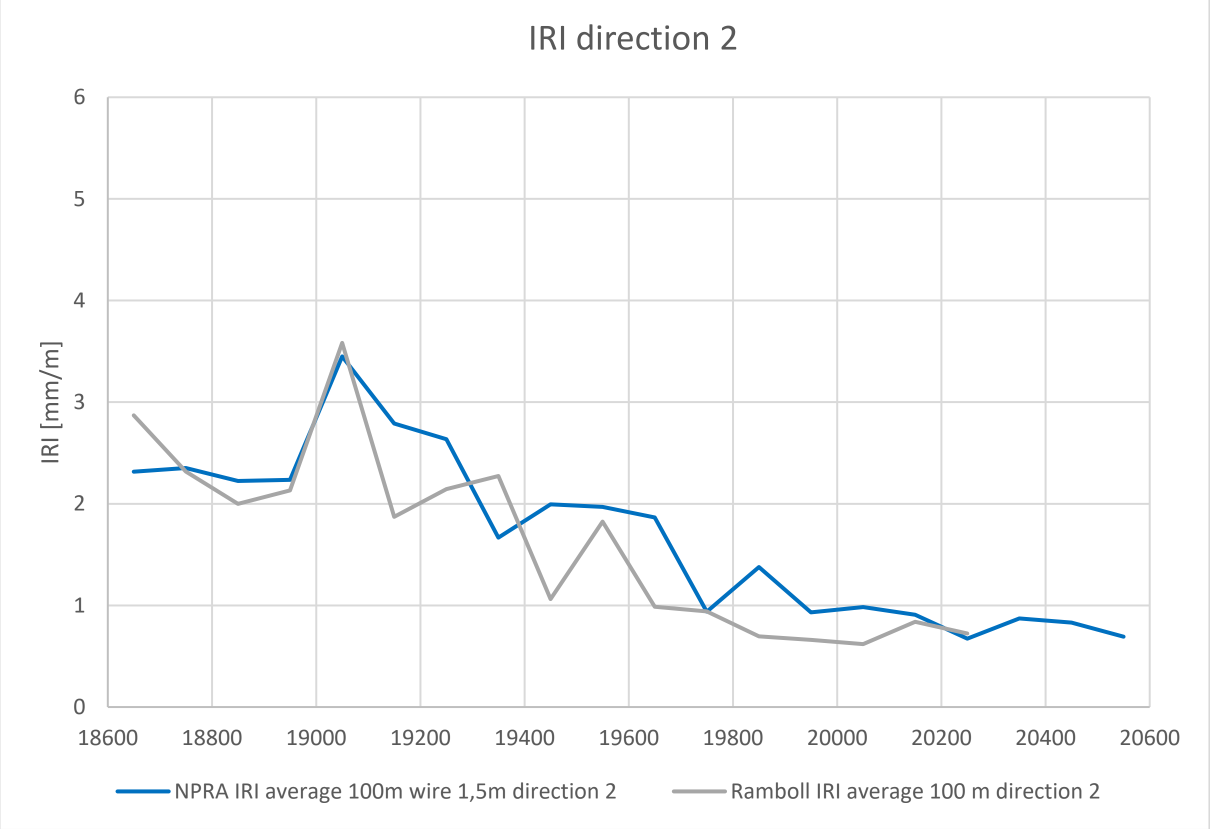


Figure 34: IRI, 1-meter segments, direction 2, Ramboll

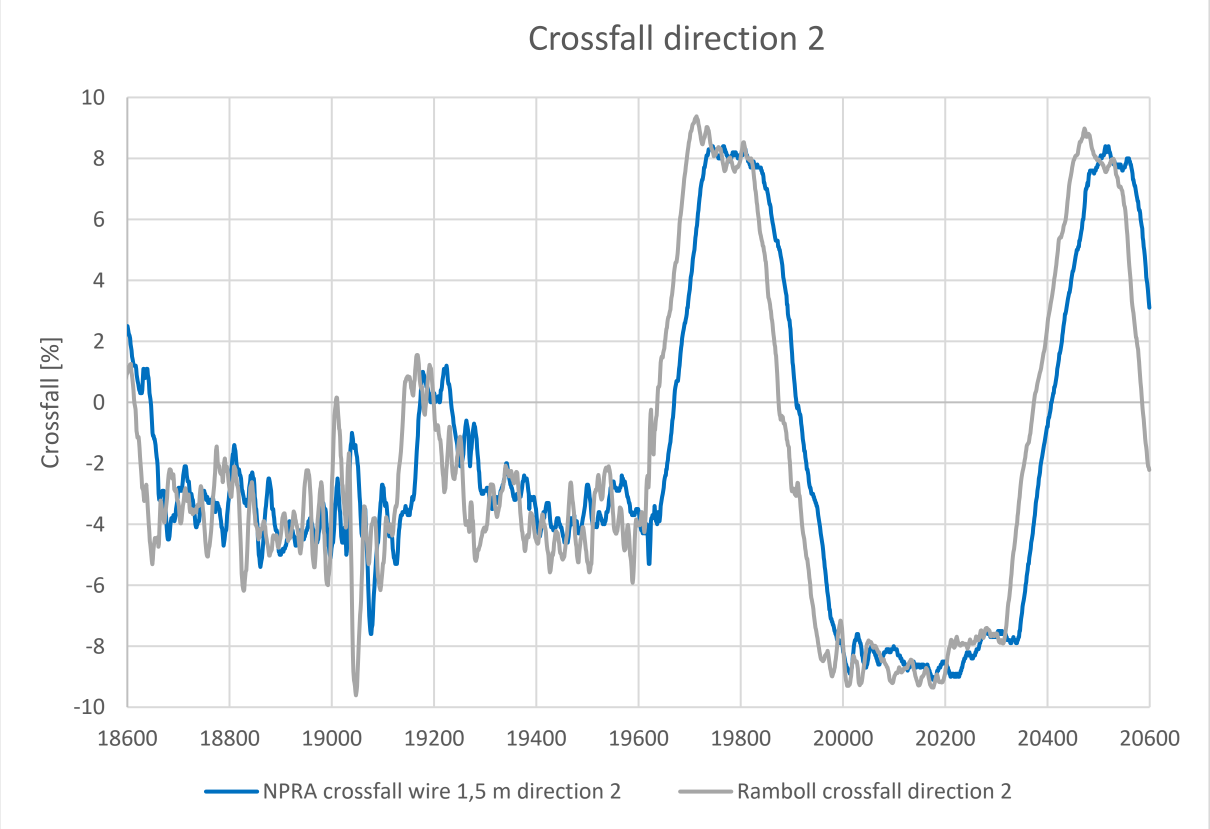


Figure 35: Crossfall, 1-meter segments, direction 2, Ramboll

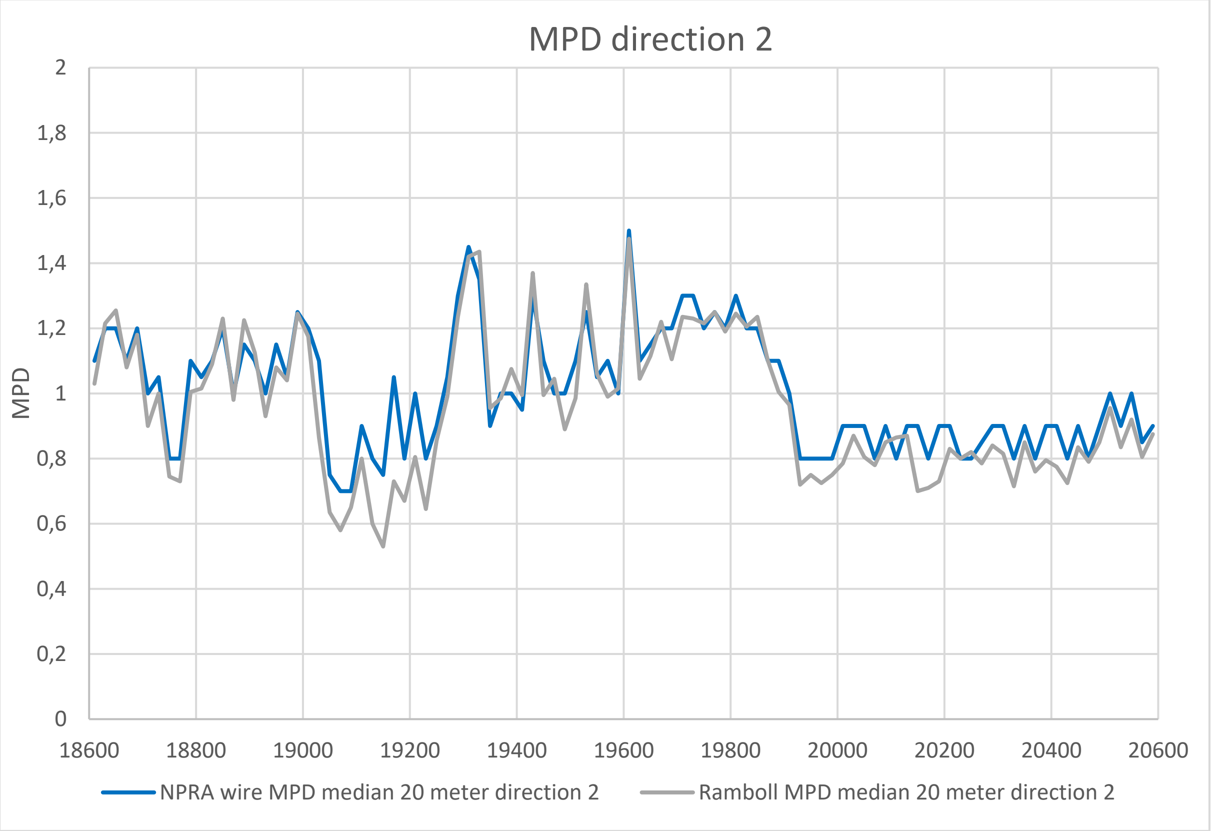


Figure 36: MPD, 1-meter segments, direction 2, Ramboll

5 Lehmann + Partner

Lehman + Partner used the Mobile Mapping System I.R.I.S 13, with the Fraunhofer Pavement profile Scanner PPS+. The PPS+ has two integrated laser sensors; 3D unit and 2D unit, where the 2D measurements have a much higher resolution than 3D. The 2D laser scanner has a resolution of 1,7*1,2 mm at 80 km/h [9].

Rutting was calculated with the ridge height method, using a virtual reference bar of 2 m. The lane is separated into two parts, left and right rut depth. The largest of all temporally stored maximum depths is used. The rutting value is averaged for every 1 m.

IRI was calculated using the quarter car method based on 10 cm raw support point's profile. The 20-meter segments are an average value of the 10 cm points. The 1-meter segments are median values of the 10 cm points.

Crossfall was calculated over a compensating straight from every measured transversal profile. The 20-meter value of crossfall is an average over 20 m.

All the data, except the IRI, are average values, and some discrepancies may occur because the NPRA uses median values for 20-meter segments. Lehmann + Partner's data report can be viewed in attachment 3.

Not all data presented from Lehmann + Partner are used in this report. In addition to the presented parameters, Lehmann + Partner's system also detects/describes:

- Potential water depth in left and right wheel path.
- Corridor clearance analysis (tunnels, wire/power cable, overpasses, signs, etc.)

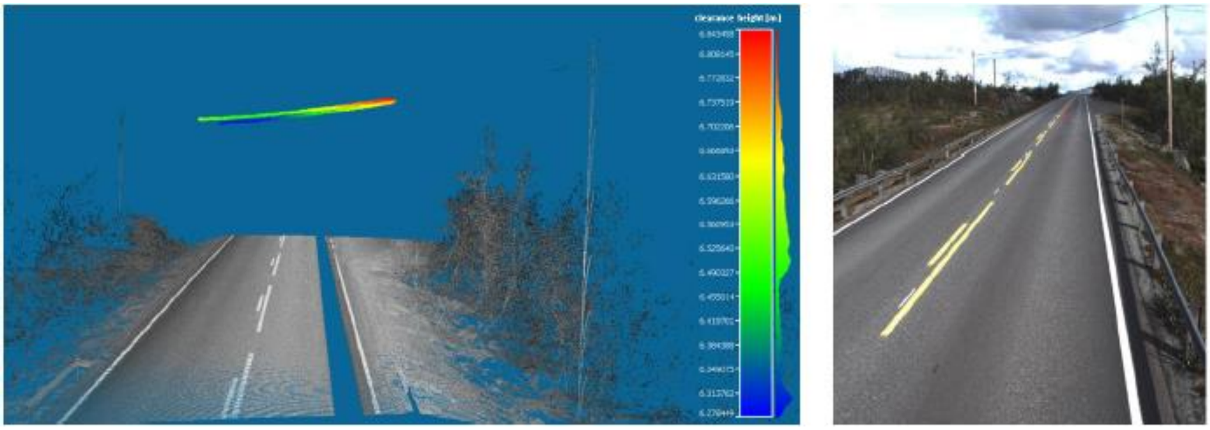


Figure 37: Clearance analysis. [9]

- Surface damages (cracks, potholes, patches, bleeding, open construction seams, etc.).

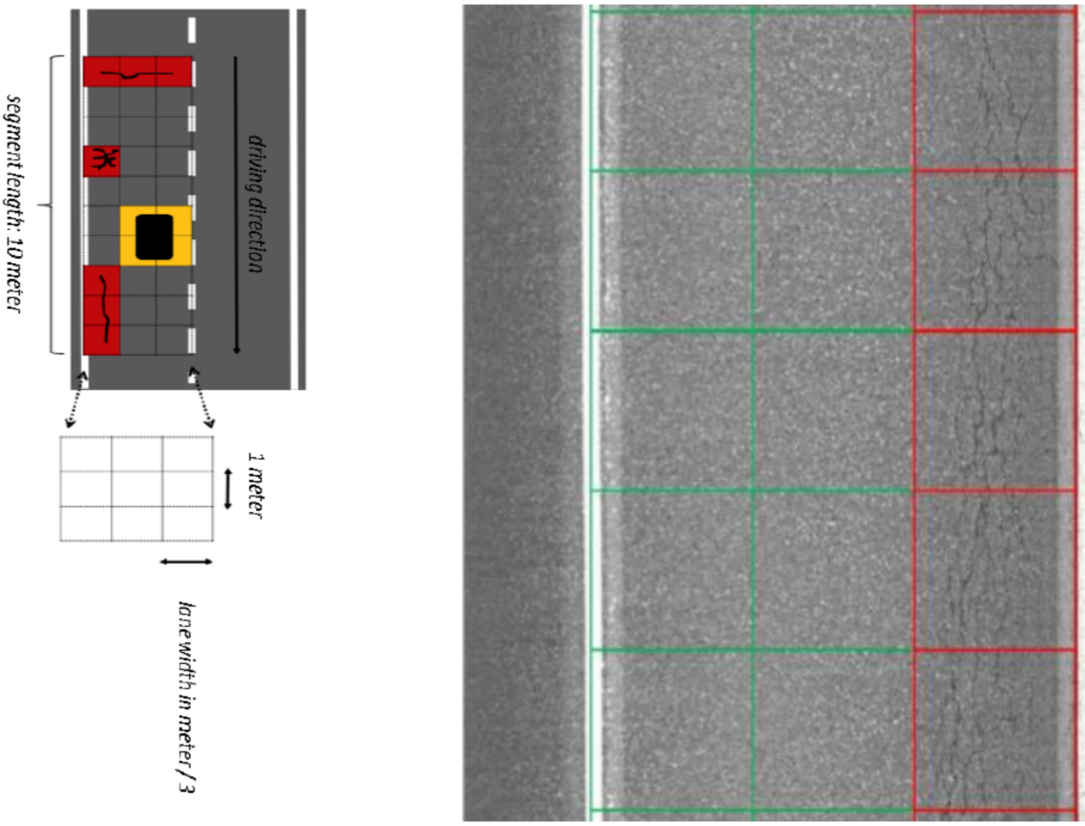


Figure 38: Picture 1 crack damages. [9]

- Corridor clearance analysis (tunnels, wire/power cable, overpasses, signs, etc.)

Figure 39: Lehmann + Partner measurement van [9]

5.1 20-meter segments

5.1.1 Direction 1 from the Finnish border - Skibotn

The starting point of the selected section was adjusted by -153 m. This gives a good correlation to the NPRA data.

The starting point for the entire measured was adjusted by -160 m. The data correlate good to the NPRA data, but over the length of the section a small scaling difference occur. Lehmann + Partner's data are offset by -20 m at the end of the entire measured section.

A shape file was attached, and it shows that the measurements started on the Finnish side of the border and ended on E6. The reason for the scaling difference could be the recalculated station by the post processing of the positioning system. The system calculates a special section DMI calibration factor, based on the combined GNNS Data and IMU Data. Therefore, the DMI´s calibration factor is partly corrected over the measurement track.

Table 9: Overview, 20-meter segments, direction 1, Lehmann + Partner

NPRA wire 1,5 m											
From	to	Rutting average	Rutting median	Rutting Std	Rutting 90 %	Rutting 50 %	IRI average	IRI median	IRI std	IRI 90 %	IRI 50 %
18600	19600	6,2	5,5	2,7	10,2	5,5	2,4	2,4	0,7	3,4	2,4
19600	20600	4,3	4,0	1,0	5,9	4,0	1,2	1,0	0,7	2,0	1,0
Lehmann + Partner											
From	to	Rutting average	Rutting median	Rutting Std	Rutting 90 %	Rutting 50 %	IRI average	IRI median	IRI std	IRI 90 %	IRI 50 %
18600	19600	2,8	2,4	1,4	4,0	2,4	1,9	1,7	0,7	2,6	1,7
19600	20600	2,4	2,3	0,9	3,2	2,3	0,8	0,7	0,6	1,7	0,7

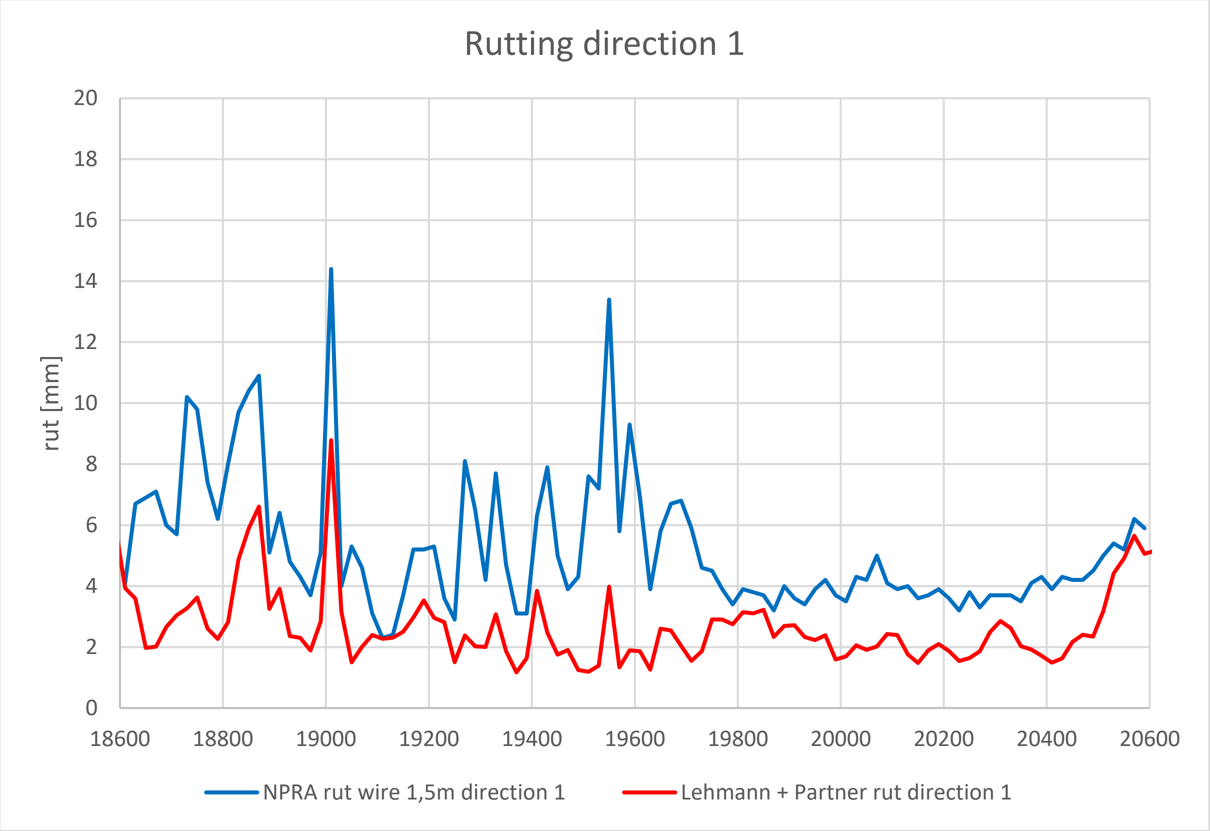


Figure 40: Rutting, 20-meter segments, direction 1, Lehmann + Partner

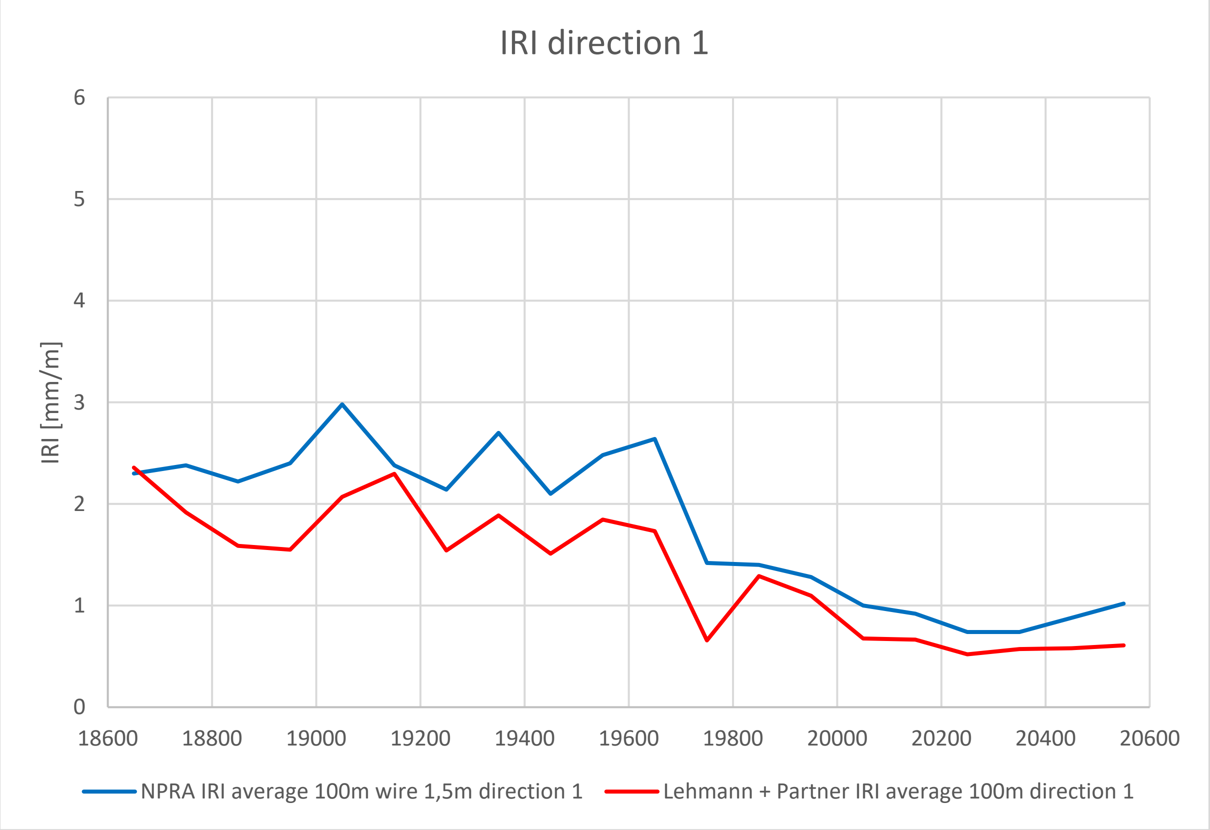


Figure 41: IRI, 20-meter segments, direction 1, Lehmann + Partner

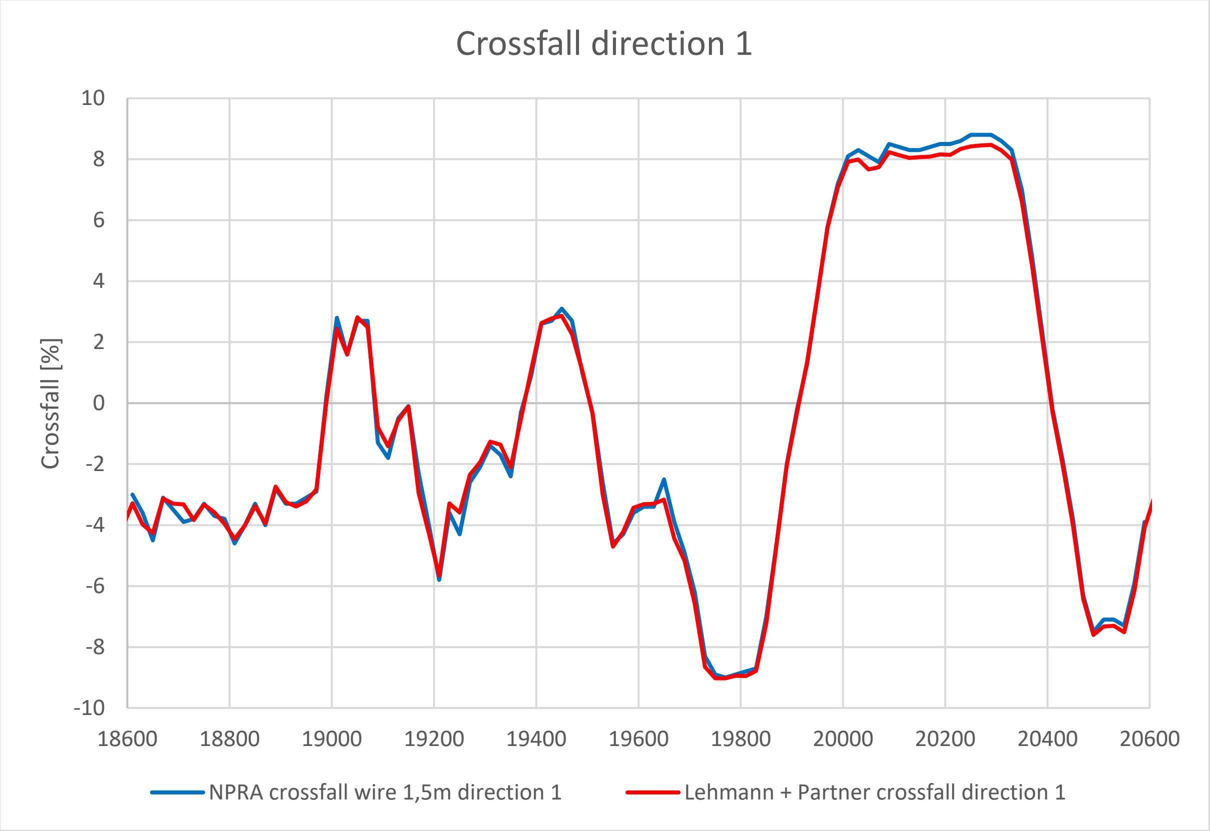


Figure 42: MPD, 20-meter segments, direction 1, Lehmann + Partner

5.1.2 Direction 2 from Skibotn – Finnish border

The starting point of the selected section was adjusted by -153 m. This gives a good correlation to the NPRA data.

The stating point of the entire measured section was adjusted by -160 m. The data correlate good to the NPRA data, but over the length of the section a small scaling difference occur. Lehmann + Partner's data are offset by -20 m at the end of the entire measured section.

Table 10: Overview, 20-meter segments, direction 2, Lehmann + Partner

NPRA wire 1,5 m											
From	to	Rutting average	Rutting median	Rutting Std	Rutting 90 %	Rutting 50 %	IRI average	IRI median	IRI std	IRI 90 %	IRI 50 %
18600	19600	8,0	7,4	2,7	11,8	7,4	2,4	2,0	1,0	3,8	2,0
19600	20600	5,6	5,5	1,1	6,6	5,5	1,0	0,8	0,7	1,9	0,8
Lehmann + Partner											
From	to	Rutting average	Rutting median	Rutting Std	Rutting 90 %	Rutting 50 %	IRI average	IRI median	IRI std	IRI 90 %	IRI 50 %
18600	19600	3,9	3,9	1,8	6,0	3,9	2,1	1,8	1,0	3,0	1,8
19600	20600	2,7	2,8	0,7	3,6	2,8	0,9	0,7	0,7	1,6	0,7

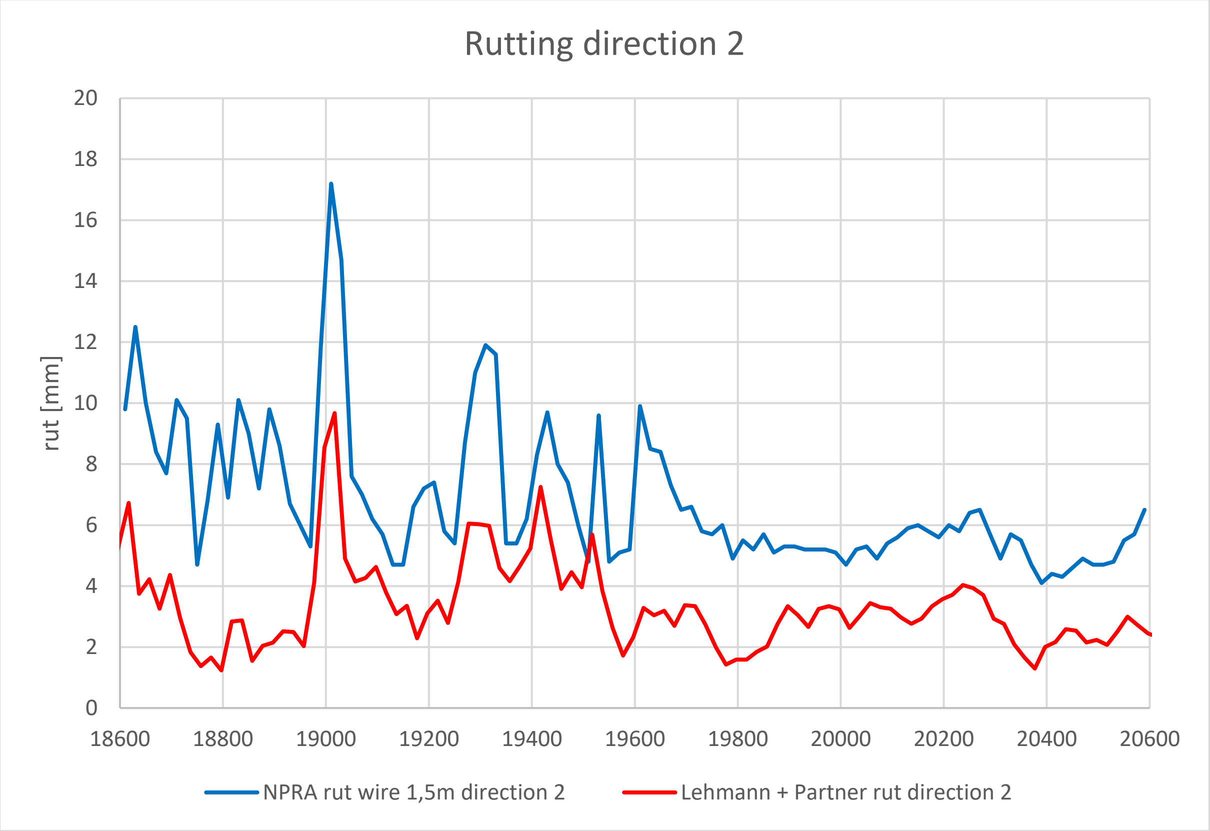


Figure 43: Rutting, 20-meter segments, direction 2, Lehmann + Partner

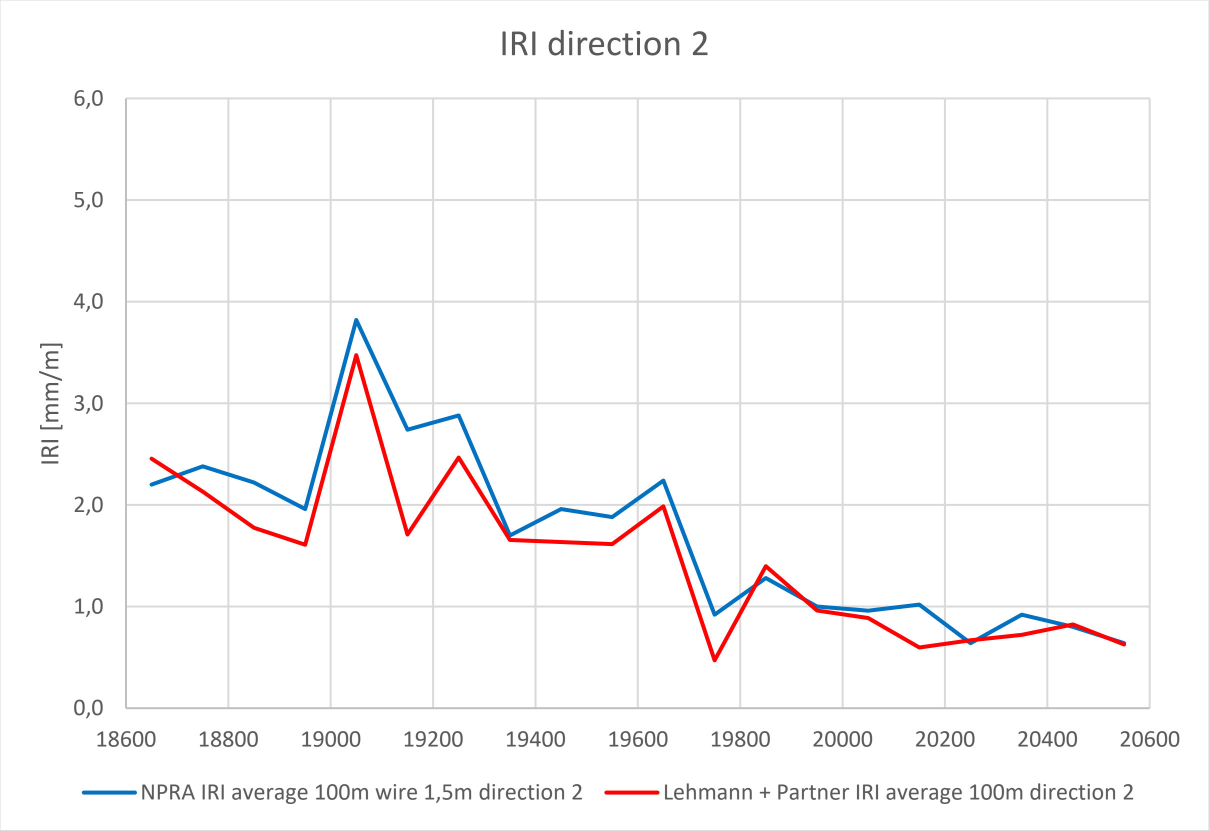


Figure 44: IRI, 20-meter segments, direction 2, Lehmann + Partner

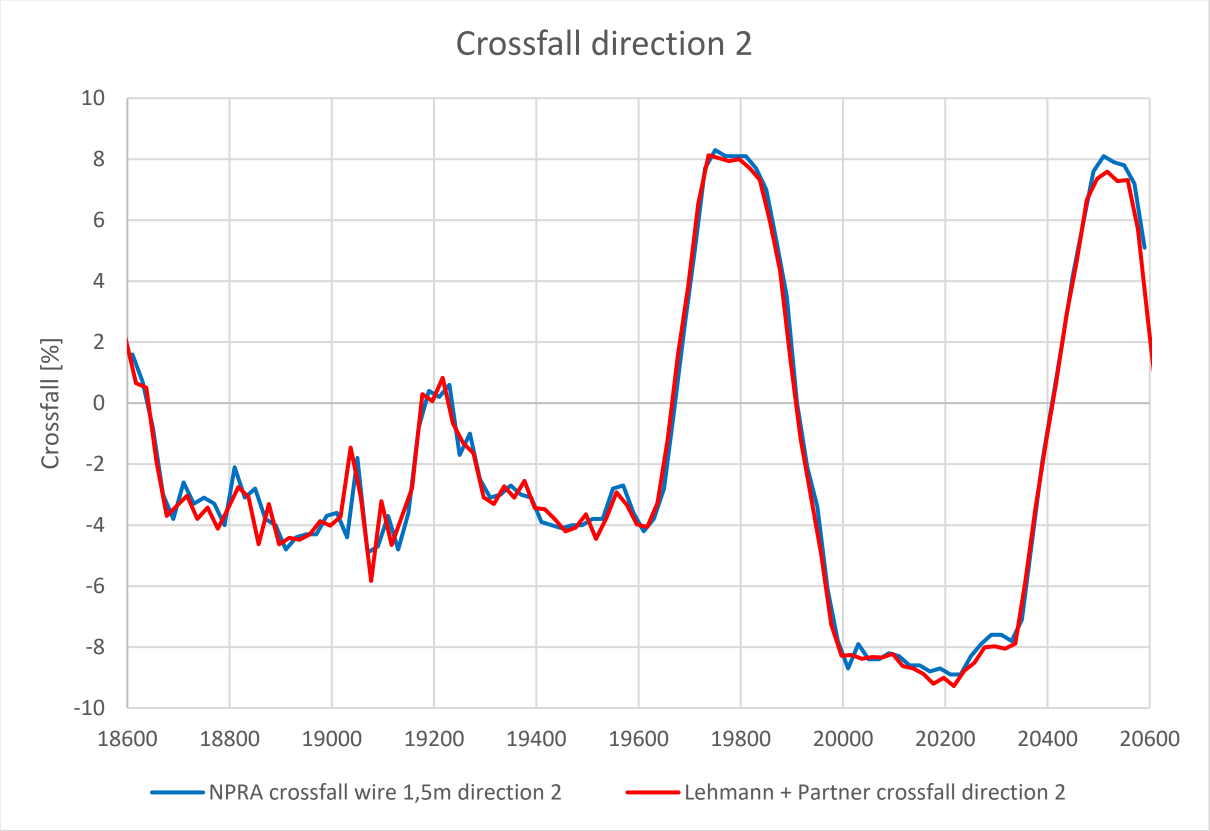


Figure 45: Crossfall, 20-meter segments, direction 2, Lehmann + Partner

5.2 1-meter segments

5.2.1 Direction 1 from the Finnish border – Skibotn

The starting point of the selected section was adjusted by -156 m. This gives a good correlation to the NPRA data.

For the entire measured section, the starting point was adjusted by an offset of -156 m. This gives a good correlation in the middle of the entire measured section, but the data are offset in the beginning and the end. No scaling factor was applied.

Table 11: Overview, 1-meter segments, direction 1, Lehmann + Partner

NPRA wire 1,5 m											
From	to	Rutting average	Rutting median	Rutting Std	Rutting 90 %	Rutting 50 %	IRI average	IRI median	IRI std	IRI 90 %	IRI 50 %
18600	19600	6,3	5,6	3,0	10,3	5,6	2,3	2,2	0,7	3,4	2,2
19600	20600	4,3	4,1	1,1	5,9	4,1	1,2	1,0	0,7	2,1	1,0
Lehmann + Partner											
From	to	Rutting average	Rutting median	Rutting Std	Rutting 90 %	Rutting 50 %	IRI average	IRI median	IRI std	IRI 90 %	IRI 50 %
18600	19600	6,2	5,2	3,5	10,5	5,2	2,3	1,8	1,8	4,5	1,8
19600	20600	3,9	3,6	1,2	5,6	3,6	1,0	0,8	1,1	1,9	0,8

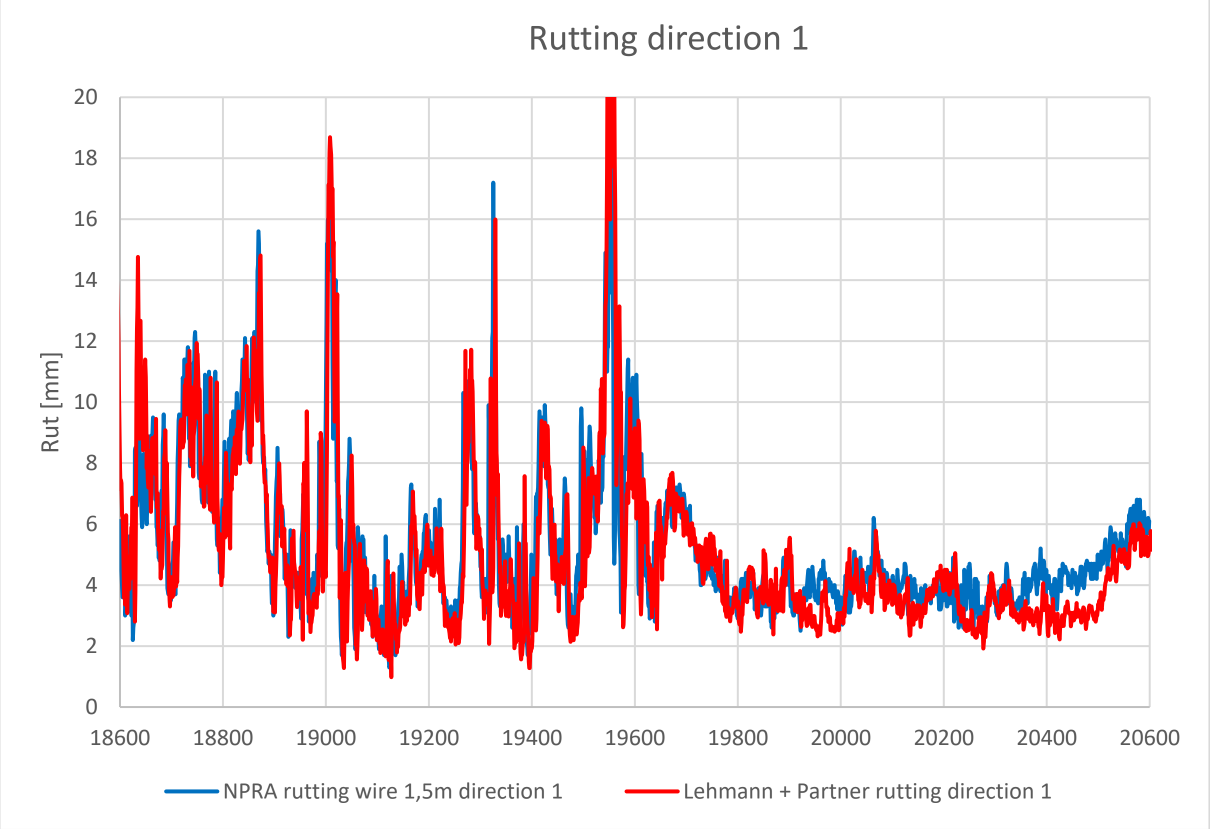


Figure 46: Rutting, 1-meter segments, direction 1, Lehmann + Partner

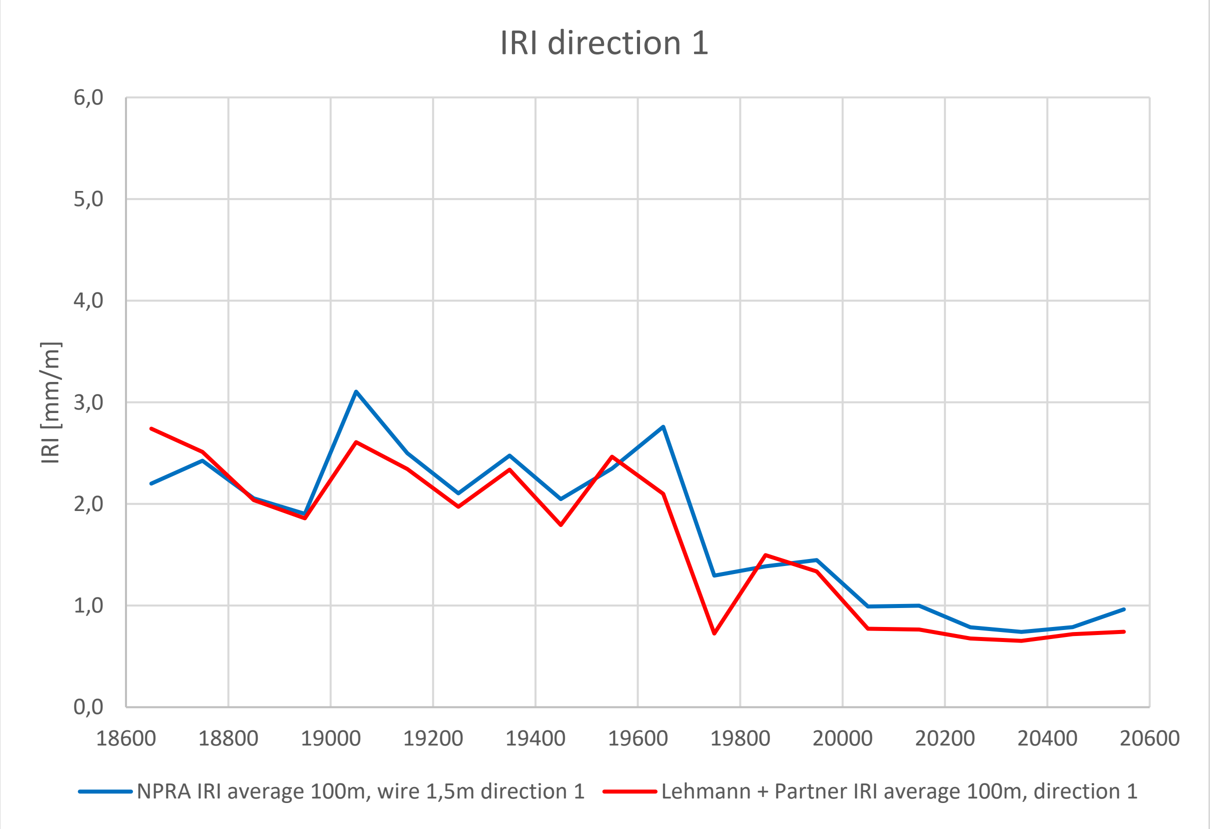


Figure 47: IRI, 1-meter segments, direction 1, Lehmann + Partner

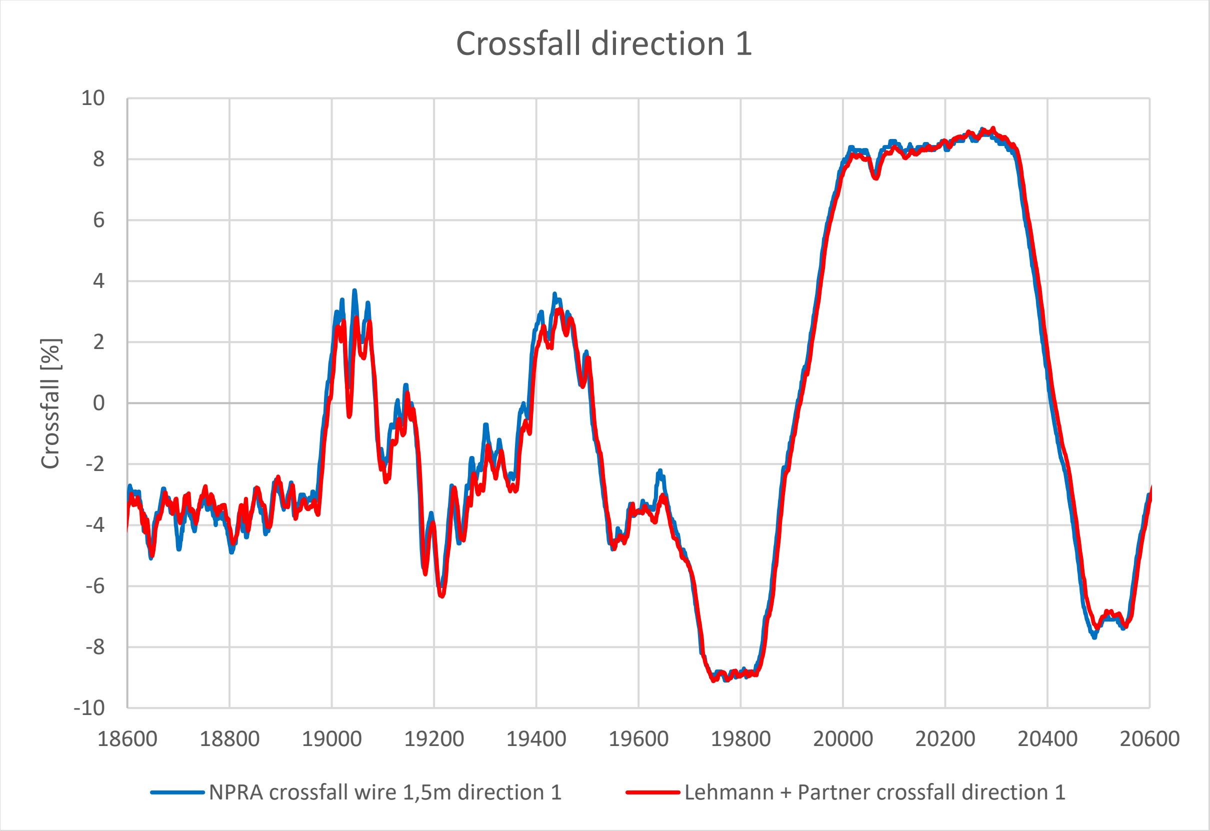


Figure 48: Crossfall, 1-meter segments, direction 1, Lehmann + Partner

5.2.2 Direction 2 from Skibotn - Finnish border

The starting point of the selected section was adjusted by -153 m. This gives a good correlation with the NPRA data.

For the entire measured section, the starting point was adjusted by -153 m. This gives a good correlation with the NPRA in the middle section, but the data are offset in the beginning and at the end. A scaling factor was not applied.

Table 12: Overview, 1-meter segments, direction 2, Lehmann + Partner

NPRA wire 1,5 m											
From	to	Rutting average	Rutting median	Rutting Std	Rutting 90 %	Rutting 50 %	IRI average	IRI median	IRI std	IRI 90 %	IRI 50 %
18600	19600	8,1	7,4	3,1	12	7,4	2,4	2,2	0,9	3,7	2,2
19600	20600	5,8	5,5	2,2	6,7	5,5	1,0	0,8	0,6	1,5	0,8
Lehmann + Partner											
From	to	Rutting average	Rutting median	Rutting Std	Rutting 90 %	Rutting 50 %	IRI average	IRI median	IRI std	IRI 90 %	IRI 50 %
18600	19600	8,3	7,6	3,3	12,9	7,6	2,4	1,9	2,1	4,9	1,9
19600	20600	4,6	4,2	2,4	6,0	4,2	1,1	0,8	1,2	2,0	0,8

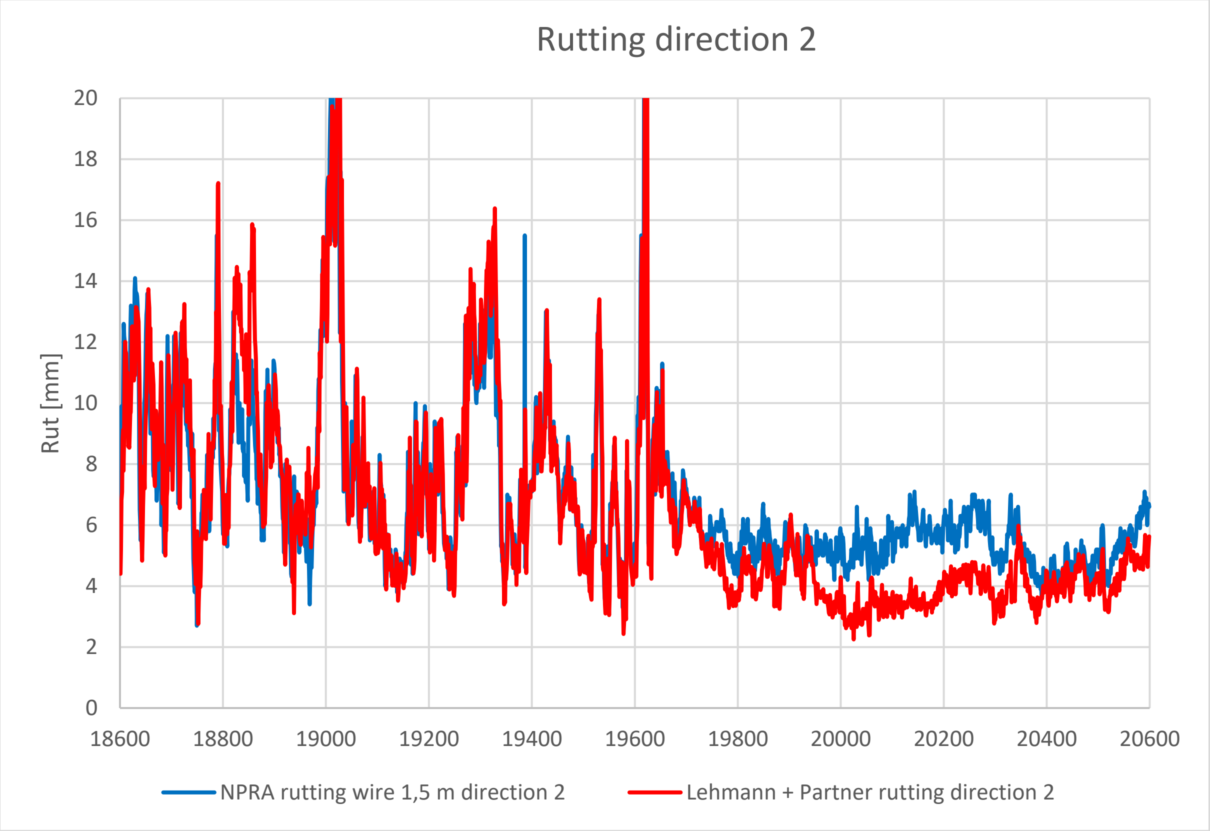


Figure 49: Rutting, 1-meter segments, direction 2, Lehmann + Partner

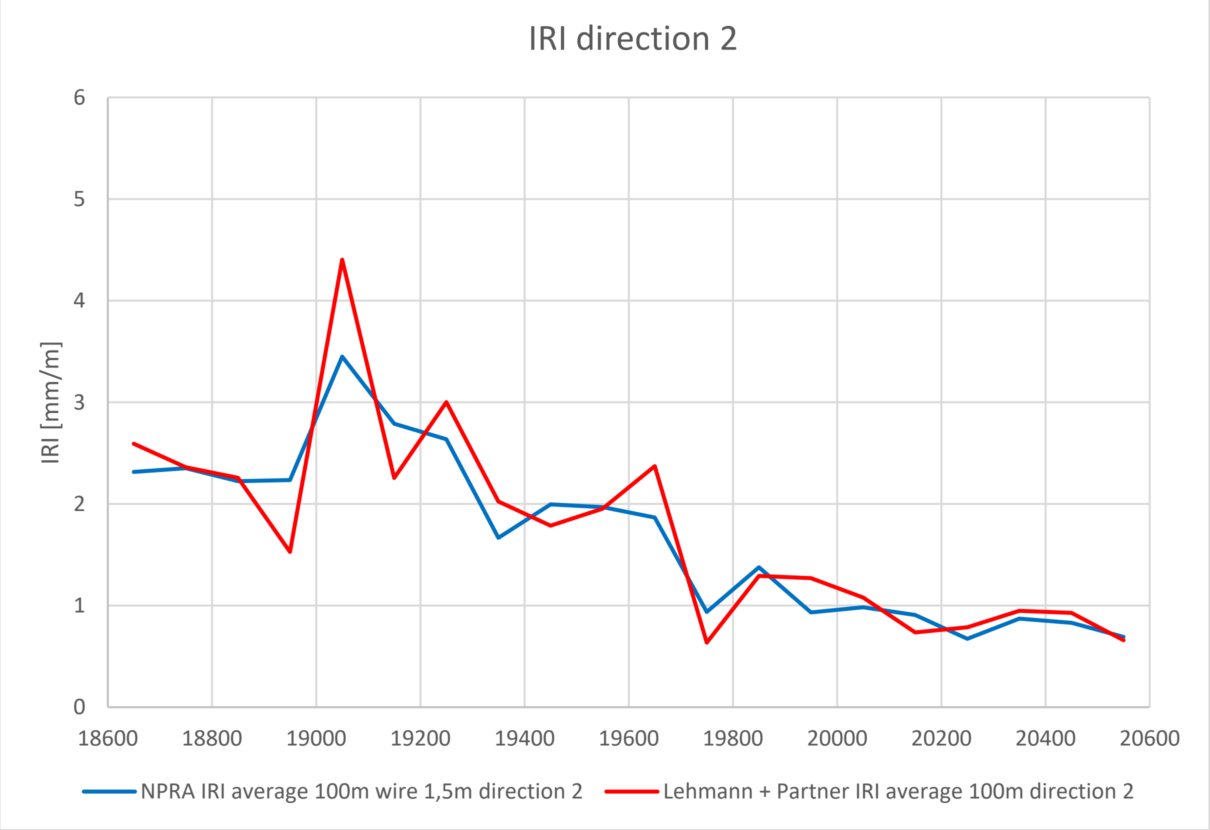


Figure 50: IRI, 1-meter segments, direction 2, Lehmann + Partner

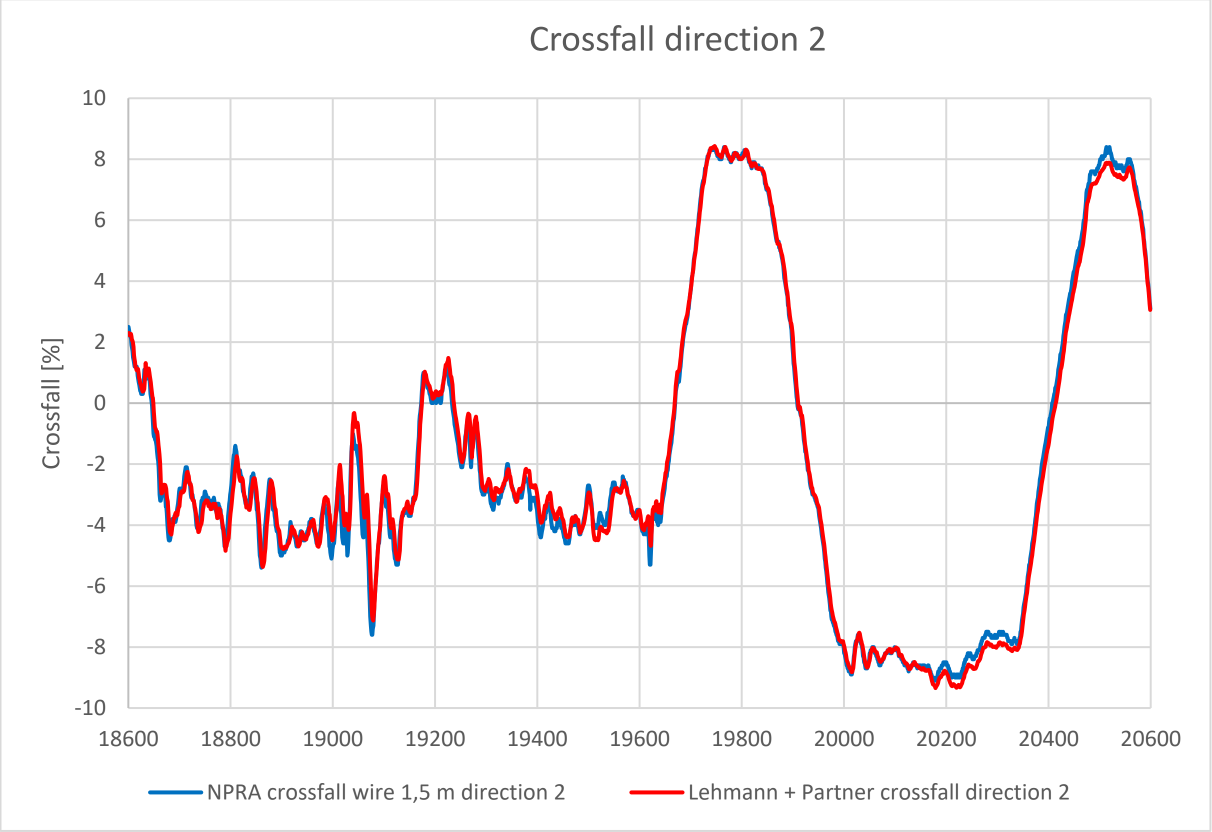


Figure 51: Crossfall, 1-meter segments, direction 2, Lehmann + Partner

6 Terratec

Terratec used the Optech Lynx SG1 Mobile mapper, consisting of two slanted 600 kHz lasers, with a precision for the distance of ± 0,5 cm (1 sigma). This system is optimized for scanning side terrain and objects alongside the road. Therefore, this system is not suitable for IRI and rutting measurements. From the delivered data only crossfall can be used in this study. The calculation method for crossfall was not stated in the report. [10]

Terratec's data report can be viewed in attachment 4.

Figure 52: Terratec measurement car [10]

The data were presented in 5-meter segments. The median values of these 5-meter segments were converted into 20-meter segments. Only a small section of the entire section was measured. From the GPS coordinates the measured section went from m 18 587 – 20 582 in direction 1 and 18 582 – 20 582 in direction 2.

6.1 20-meter segment

6.1.1 Direction 1 from the Finnish border – Skibotn

No adjustments were needed to get a good correlation to the NPRA data.

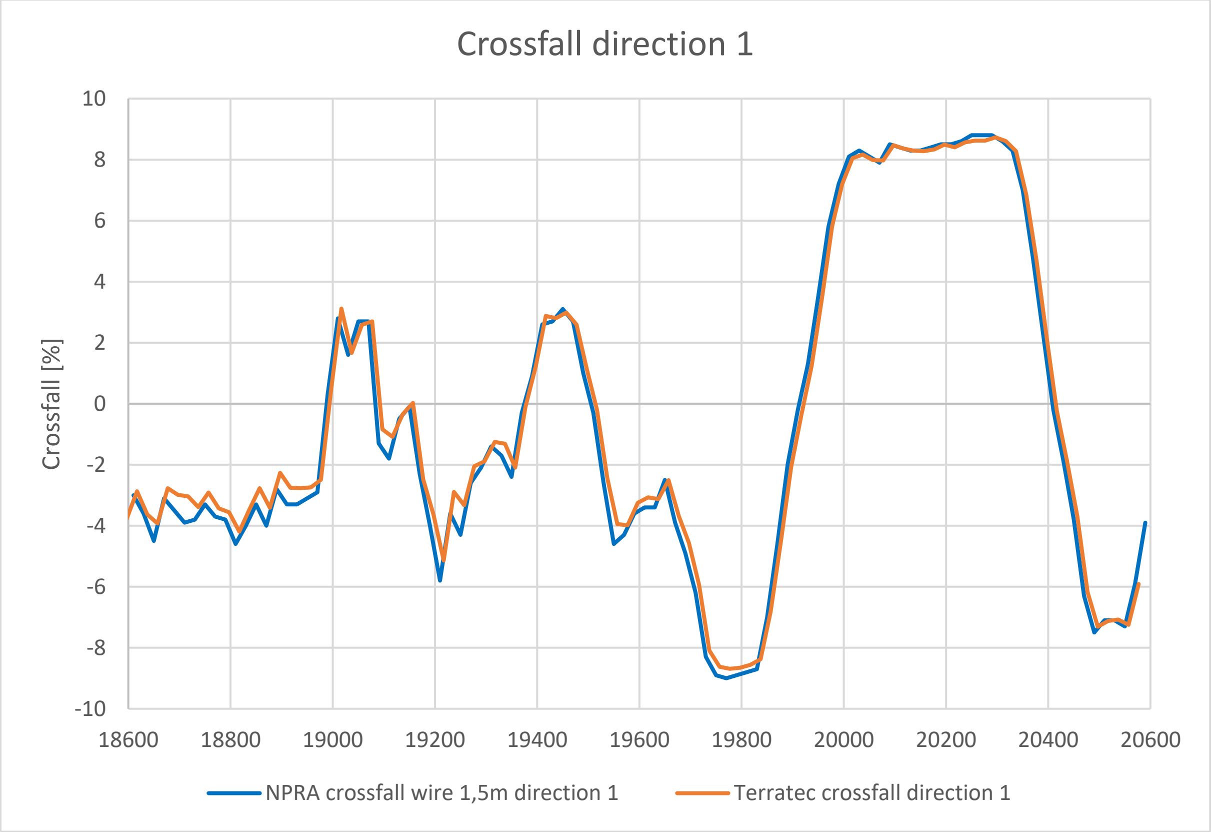


Figure 53: Crossfall, 20-meter segments, direction 1, Terratec

6.1.2 Direction 2 from Skibotn – Finnish border

No adjustments were needed to get a good correlation to the NPRA data.

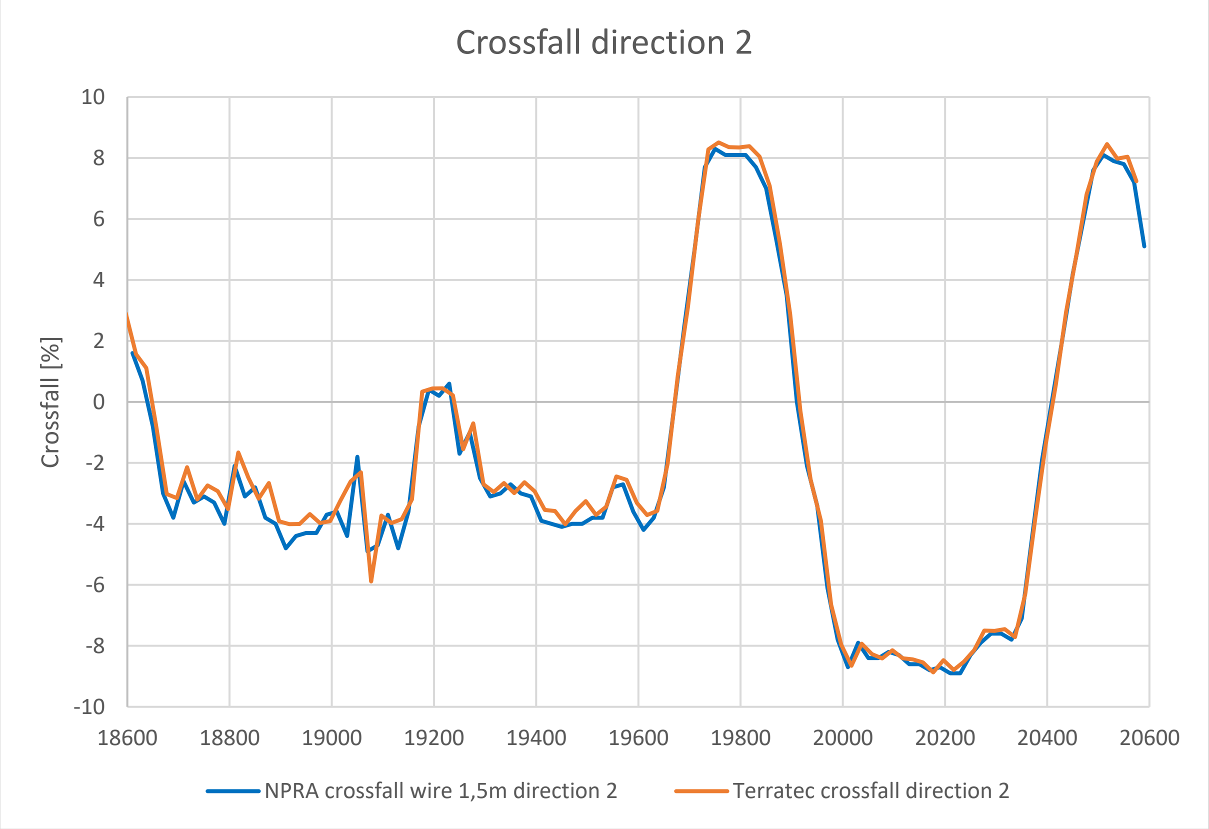


Figure 54: Crossfall, 20-meter segments, direction 2, Terratec

7 Comments/discussion

Some discrepancies will occur on the 20-meter segments due to the area that is included in the calculations. For example, the NPRA data were reported from road reference 20 m (starting location were 16 m). To eliminate these discrepancies, mainly 1-meter segments data were used for the compilation of the collected data. This made it easier to get a good correlation with the other data.

7.1 Roadscanners

As it can be seen in the figures for crossfall, the NPRA data were always “lower” in value than Roadscanners’ data. The shape of the crossfall was the same. A possible reason might be a calibration difference, since all the other participants had similar values as the NPRA.

The correlation of the data varies between the 1- and 20 meter segments, but also between direction 1 and 2 for each segment. For example the data from direction 1 for the 1 meter segment, there were problems with the scaling. For example, the data for rutting were increasingly offset from the NPRA data at meter 19325 by around 5 m, but this effect is reversed from around meter 21 000 and the data show a good correlation at the end of the measurements. For direction 2, a scaling factor of +32 m was used. This gave a good correlation to the NPRA data. Both the NPRA data and Roadscanners’ data should have been calibrated based on GPS signal, so the data should have shown a better correlation.

The average, median and 90/10 values for the selected section showed that the data have a good correlation, with only small differences in values. Based on the different calculation methods, these discrepancies were within the expected range.

7.2 Ramboll

To compare the data from Ramboll to NPRA an offset and a scaling factor had to be applied to Ramboll’s data. This made a direct comparison of the results possible for the selected area. However, when the entire section was evaluated, the correlation was rather poor. The start and end point and the scaling between should be reconsidered. The GPS coordinates were used to give an approximately start and end point, compared to the road reference that is used in Norway. The length of the measured sections is longer than the distance between the start/ending points given by the GPS. Also, in the 1-meter data for direction 2 that were delivered from meter 31396, the exact same data were copied in 27 rows. If the same error has occurred in the 20-meter segments as well, this can be part of the reason for the quite large errors in total length. These data have been removed from the 1-meter segments, and the numbering was continued from there. It should be reviewed whether continuing the numbering or shifting the data is the better solution.

Discrepancy between the starting point for rutting, IRI and MPD versus crossfall for direction 2. While the data for rutting, IRI and MPD had a good correlation, the crossfall data are offset in the beginning.

There was also a discrepancy in direction 2, between what the starting meter of crossfall and rutting/IRI/MPD should have been. Since all data were collected simultaneously, this difference is hard to explain.

The average, median and 90/10 values for the selected section showed that the data had a good correlation on the newly built section, with only small differences in values. On the older section there are larger discrepancies than expected. The overall trend of the graphs is the same, but Ramboll’s measurements gave smaller values.

7.3 Lehmann + Partner

Lehmann + Partner’s data had mostly a good correlation with the NPRA data, but a small scaling factor had to be applied over the length of the section. For the 20-meter segments, some differences were expected, since all the NPRA data were median values for each 20-meter segment, while Lehmann + Partner’s data were averaged. Some of the differences occurred because different data sets were included in the calculations.

Rutting calculated from the 20-meter segments showed big differences, compared to data for 1-meter segments. As shown in the tables for Lehmann + Partner, the rutting values for 20-meter segments were considerably lower than on the 1-meter segments. Rutting was calculated the same way for both segments.

7.4 Terratec

There were some discrepancies between the measured NPRA crossfall data and Terratec’s data. These discrepancies were mostly in direction 2, and this can probably originate in the fact that the laser data from direction 1 were used to interpret data in direction 2. Since NPRA and Terratec used different intervals to calculate data (NPRA used 18600 – 18 620 and Terratec used 18 605 – 186 25), some discrepancies were expected.

7.5 Quality of data/laser scanners

Based on the results it is hard to determine if one (or more) of the systems had a better quality on the result than the other systems. Different calculation methods were used; therefore, a direct comparison was challenging. To make a direct comparison of data possible, all data should have been calculated in the same way.

This study was mostly limited to evenness, rutting and crossfall (only one participant delivered MPD data). Since all these parameters are presented as median/average values over 1-meter segments and 20-meter segments, the accuracy of the laser scanners is less important. Each survey has only been performed once, so the repeatability of the systems has not been investigated.

7.6 Further work

For further work all systems should deliver raw data, so that the NPRA (our other consultants) can review and analyse in a single system. Also, the following parameters should be investigated more thoroughly for different systems:

- Texture (booth MPD and mega texture)
- Homogeneity
- Surface damages and crack detection.

The repeatability of the different systems should also be considered.

8 References

[1] *Picture taken for NPRA home web page for E8 Borealis,* *https://www.vegvesen.no/_attachment/2125706/binary/1228521?fast_title=ITS+illustration%3A+Transport+corridors+and+international+cooperation.jpg*

[2] «*E8 Borealis, Måling av vegoverbygning, bæreevne og grøftedybder, E8 Skibotn–Riksgrense Finland, Troms- og Finnmark fylke*», Rapport nr 707, Statens vegvesen, 2021

[3] Z+F PROFILER 9012_Datasheet_E_final.indd (zf-laser.com)

[4], *SVV handbook R211 feltundersøkelser,* *https://www.vegvesen.no/_attachment/111560/binary/1297147?fast_title=H%C3%A5ndbok+R211+Feltunders%C3%B8kelser%2C+retningslinjer+%2818+MB%29.pdf*]

[5] «*RDSV surveys E8 Borealis 2019*», Roadscanner’s 2019

[6] Search tool for report in the Swedish Transport administration, Extern visning av Dokumentcenter (trafikverket.se)

[7] Pavematrics datasheet, LCMS_Flyer.pdf (pavemetrics.com)

[8] «*Pavement measurements at E8 in Troms Norway – Ramboll RST*», Rambøll, 2019

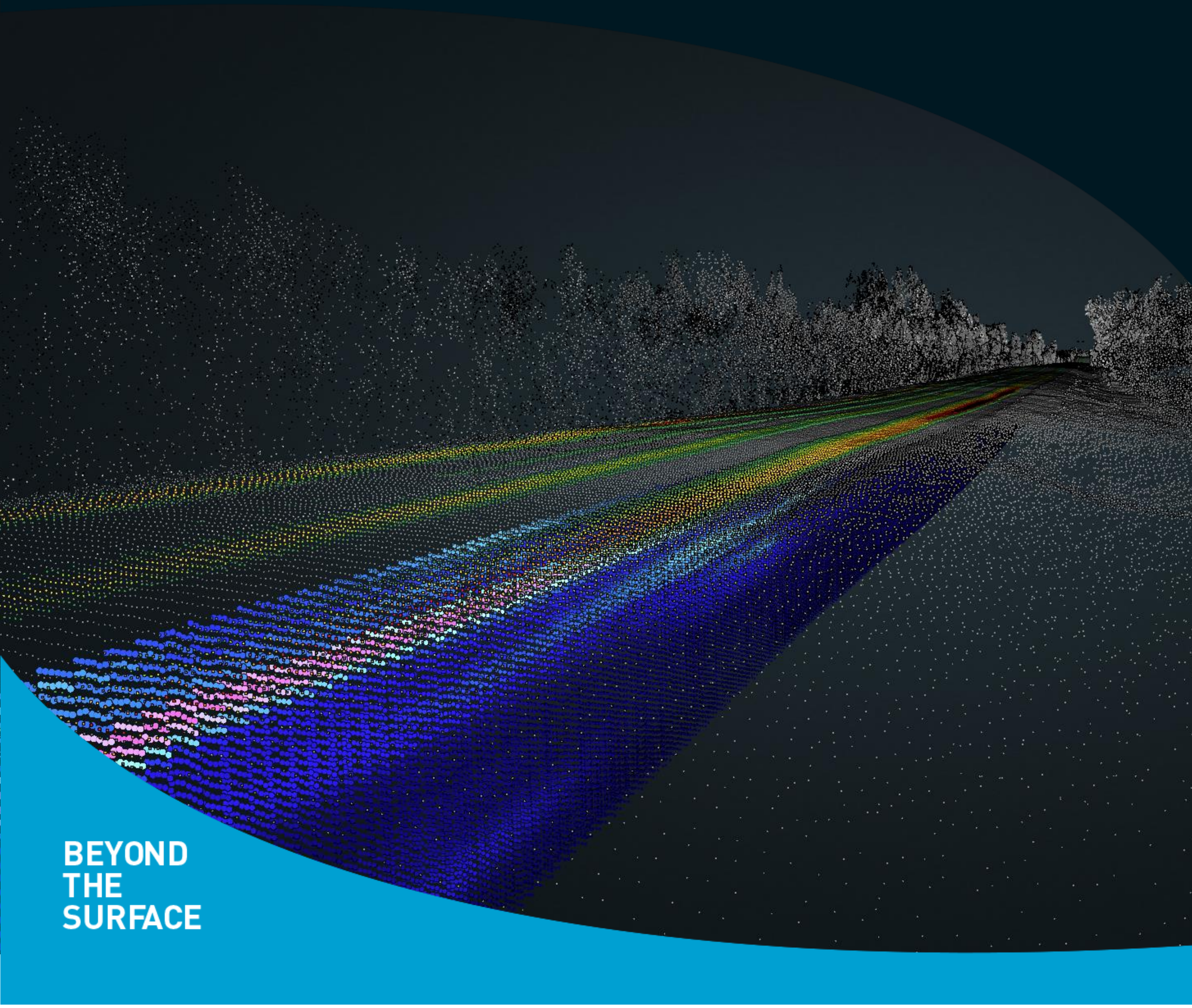
[9] «P 18-325, *3D Road condition monitoring on the arctic intelligent transport test ecosystem Borealis on E8*», Lehmann+Partner, 2019

[10] «*Leveranserapport E8 Borealis rev 002*», Terratec 2020

Attachment 1

RDSV surveys E8 Borealis

2019



RDSV surveys E8 Borealis

2019

1 Introduction

As a part of different types of system tests in September 2019 Roadscanners participated in the E8 Borealis test road surveys with Road Doctor Survey Van (RDSV). Surveyed section was on the E8 road from Finnish border to Skibotn/E6 junction (38 km). The start and end points were painted on the road. The purpose of the survey was to collect rutting data, longitudinal roughness, crossfall and surface distress among other things. Ground penetrating radar was used for layer thickness and drainage analysis through video and laser scanner was requested too.

2 Survey methods

Road Doctor Survey Van (RDSV) is a van equipped with several different devices (figure 1). For road and near environment surface shape data collection, a laser scanner is installed in the rear of the vehicle at 3 m height. This device (Sick LMS500) rotates at 100 Hz rate and records distance and reflectivity of the returned laser beam. As the vehicle moves, a continuous surface image is created. The accuracy is less than 1 mm, density in average is 1 cm in cross sectional direction and in longitudinal direction approximately 10 cm on average survey speed. The distance covered is roughly 20 m and 270 degrees. In this test two laser scanners were attached to cover full 360 degrees.

The CamLink video-logging system was installed on the roof of the van. The GPS device model used for positioning was a Novatel FlexPak 6 equipped with Inertial Measurement Unit (IMU) and virtual reference station (VRS) correction. All the data was linked to GPS using Road Doctor™ CamLink software. Two video cameras were used to record the view of the road and the ditch.

The 3D accelerometer installed on the back axle of the survey vehicle provides information on the road roughness such as acceleration, IRI, cross fall and warping risk.

Road Doctor Survey Van can collect ground penetrating radar data at the same time with other devices. In this project, a GSSI SIR-30 central unit with 2 GHz and 400 MHz antenna was used to determine layer thicknesses of the road in both directions (outer wheel paths). Data was collected 10 scans per meter.

Figure 1*. The Roadscanners GPR survey system equipped with a 2 GHz air coupled horn antenna and 400 MHz ground coupled antenna in the front of the vehicle. A video camera is mounted on the roof top and a laser scanner in the rear.*

3 Processing and analysis

All data was processed and interpreted with Road Doctor 3® -software. Figure 2 presents three main viewing options of point cloud: Virtual view which can be zoomed and rotated, intensity projected on road line and elevation projected on road line. Projected data view is extremely handy to present longer section of point cloud data in one view. Virtual view provides easy-to-understand view to details like culverts, bridges or road crossings. Figure 3 shows how cross section can be shown from projected data view. Laser scanner data was read to a database and the road paintings were digitized to calculate rutting values from the right position in transverse direction. Rutting values were calculated using wire method. Rutting was calculated from the area between paint lines, because there are variations in road width. It is possible to determine the calculation area also in another way, for example using standard 3.2 m width. Cross fall results were calculated from laser scanner data with linear regression between the paint lines.

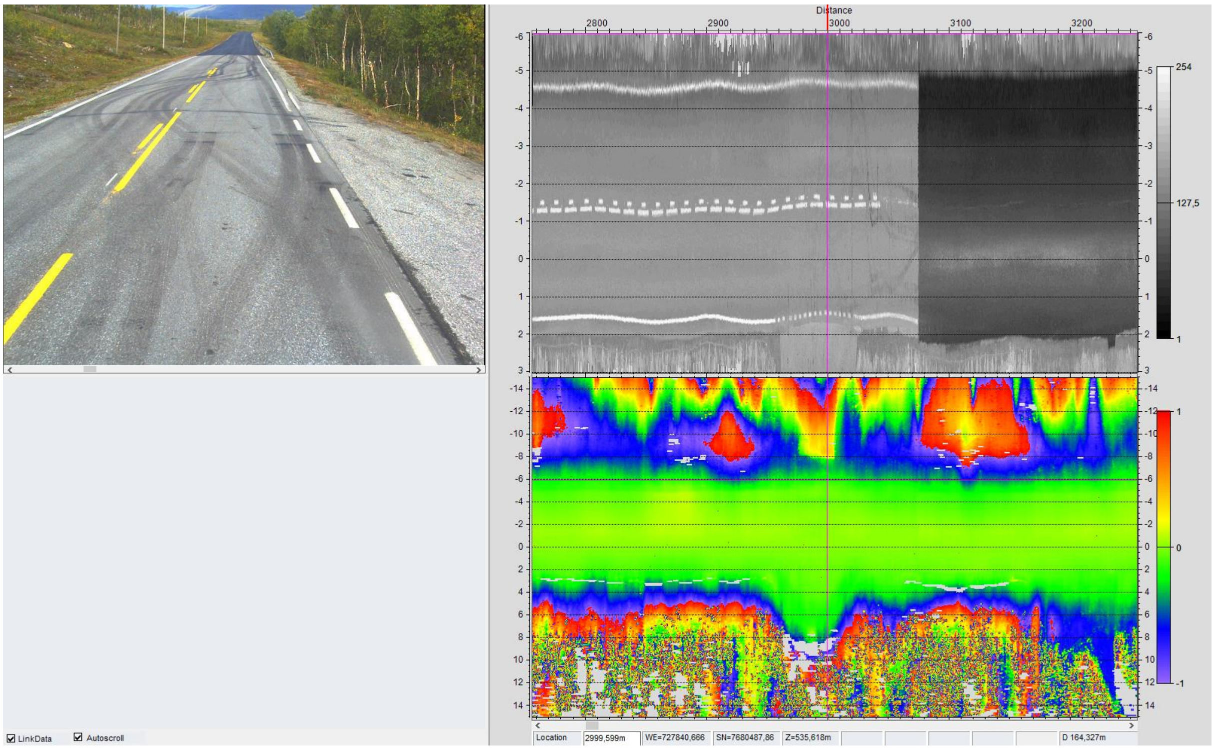


Figure 2. Road Doctor view of laser scanner data and video. On the top window the remission data from laser scanner showing the paint lines and fresh pavement starting at 3070 m. Window below shows the elevation calculated from laser scanner data.

Ditch depth and side slopes were calculated semi-automatically (fig. 3). The search tool determined the edge of the road and the ditch bottom point after the search area was given. Averaging of 10m was used to rule out single false readings. The side slope was calculated as shown in chapter 4.6.

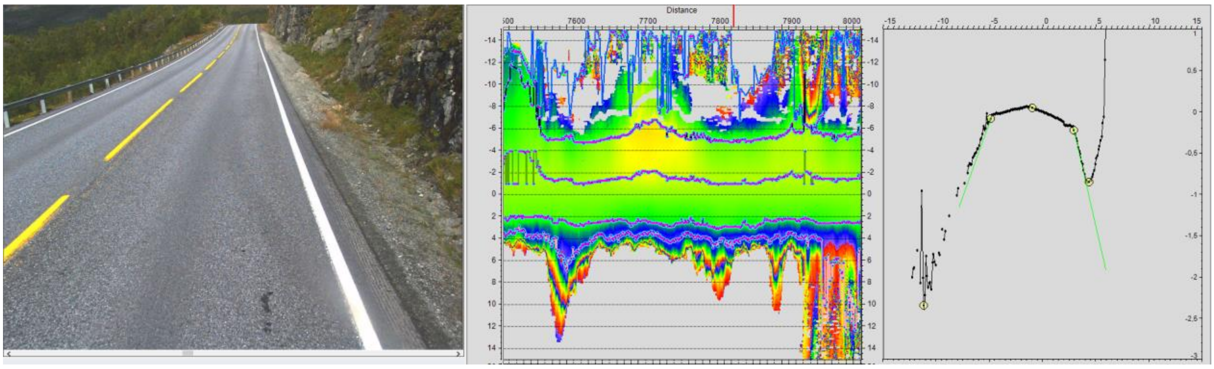


Figure 3. Road Doctor screen from ditch depth calculation. Left: video. Center: elevation from laser scanner and digitized vectors. Right: cross sectional view of laser scanner data.

Roughness data is calculated from accelerometer data. Calculation method uses the accelerometer pitch information to form IRI value (see Ch 4.3).

The digital video recordings were imported into Road Doctor 3® for integrated interpretation and analysis. The GPR interpretation carried out follows thickness of the bound layers and the overall road structure thickness. Where visible, the unbound base course and possible other layers – as old road structures were also interpreted. The embankment was also interpreted where it was found. The subgrade quality was estimated based on GPR profile, supported only by visual information from the video. At the time of delivering this report, no drill core results were available.

Drainage evaluation was based on laser scanner ditch depth. Ditch depth is compared to structure thickness (from GPR) in both directions. The results will be delivered after final interpretation of GPR data.

Surface damages are not automatically detected.

4 Results

Main tool for viewing and use of survey results is free viewer version of Road Doctor software. Idea of the Road Doctor software is to bring many kinds of datasets to the one, integrated data view. From this integrated view, it is easy to find out relationships between different datasets and analyze why certain damages is occurring. If written report is requested, it's common to take screenshots from the interesting locations and paste them to the report with explanation. It is also possible to include those Road Doctor views to report as attachment. This project deliverables includes also Excel file containing main results in 1m, 10m and 20m intervals.

As a new way of delivering results, Roadscanners has developed a new web-based mapping application, Road Data Center. It makes it easy to share results and communicate between project parties. In this project, main results are presented as thematic maps. Rutting is presented over the surface of point cloud model (fig. 4). Special new development was done for presenting moisture analysis under the road surface (fig. 5). This kind of visual presentation of both surface and subsurface data helps on understanding reasons for damages on the surface.

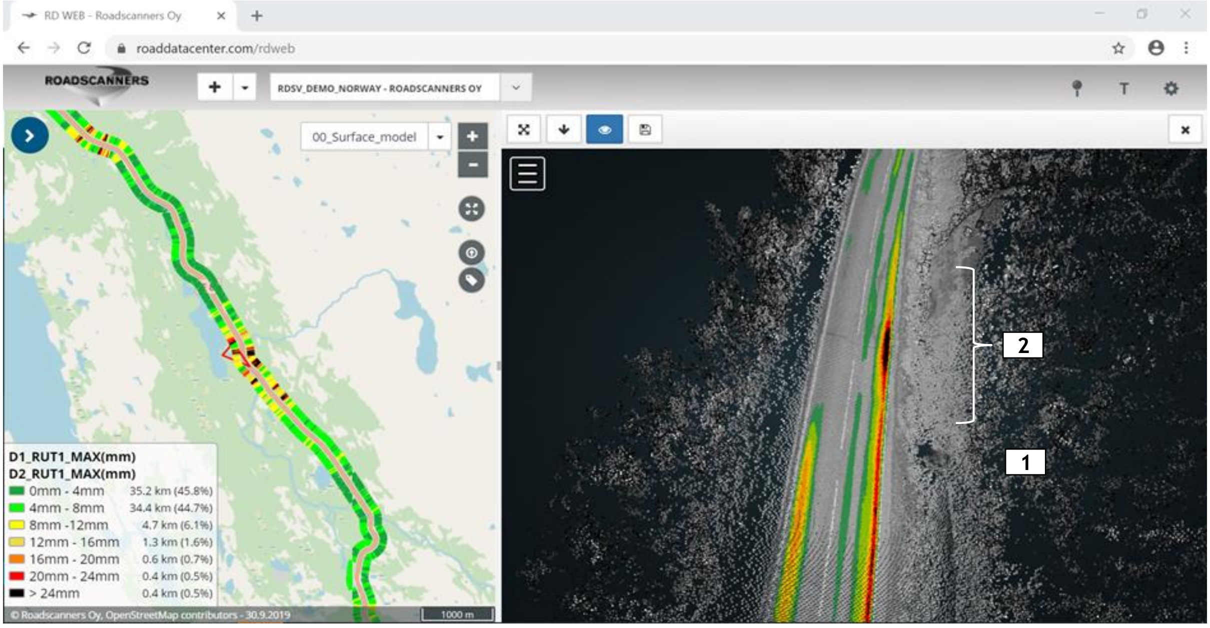


***Figure 4**. Screenshot from Road Data Center. Left side shows maximum rutting values classified in different color. Right side presents same parameter but in more details. Depth of rutting is projected to the surface of point cloud. In this specific location, culvert (1) and unclear bottom of ditch (2) can be seen close to high rutting values.*

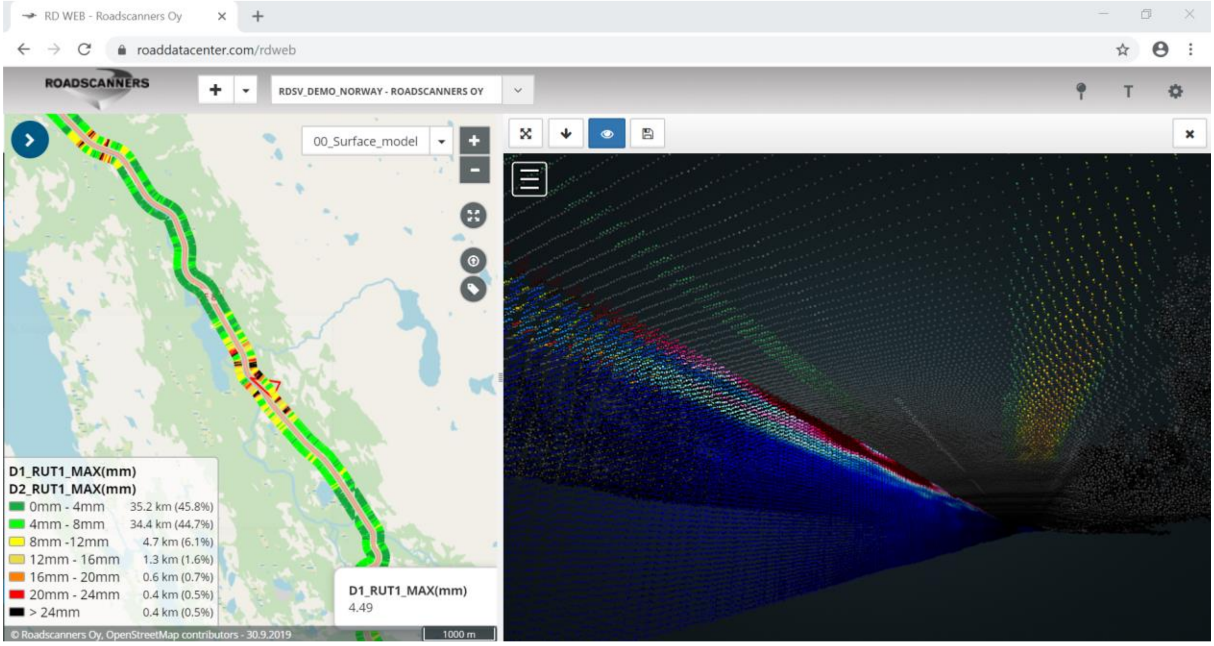


Figure 5. *Screenshot form Road Data Center like presented in Figure 10. Right side presents moisture analysis as colored point cloud calculated from ground penetrating radar measurement. Dark red indicates higher moisture compared to blue areas.*

Usage of Road Data Center is free for the members of this project but requires personal user account. Contact Roadscanners to get your access to the service.

4.1 Ditch depth calculation

Calculation of ditch depths is quite straight forward operation from point cloud data. Compared to CAD drawings and cross-sections of new road design, cross-section of existing road is changing all the time. Bottom of ditch is never straight and clear like it's in design of new road. Ditch depth calculation start by preparing point cloud to be optimal for ditch depths. This means usage of automatic filtering procedures to remove rails, traffic signs, humans and minimize the effect of grass and other small unevenness (rocks) in the road environment. To detect depth of ditch, shoulder, edge of pavement or road painting needs to be detected. From the automation point of view, road painting is preferred because it is easiest to detect. Because the road paint mark is not always on the level of the shoulder, it may cause small error to the calculation. In most cases error is smaller than effect of unevenness and grass on the slope or ditch. After point cloud is prepared (automatic process) for calculation, basic settings need to be defined: How deep ditch can be, how far it can be, what's minimum depth of ditch.

After setting correct parameters for search function, the program runs through whole section and finds main components of cross section (centerline, shoulders, ditches) automatically every 1m as shown in figure 6. By comparing elevation level of shoulder and ditch, depth of ditch can be calculated.

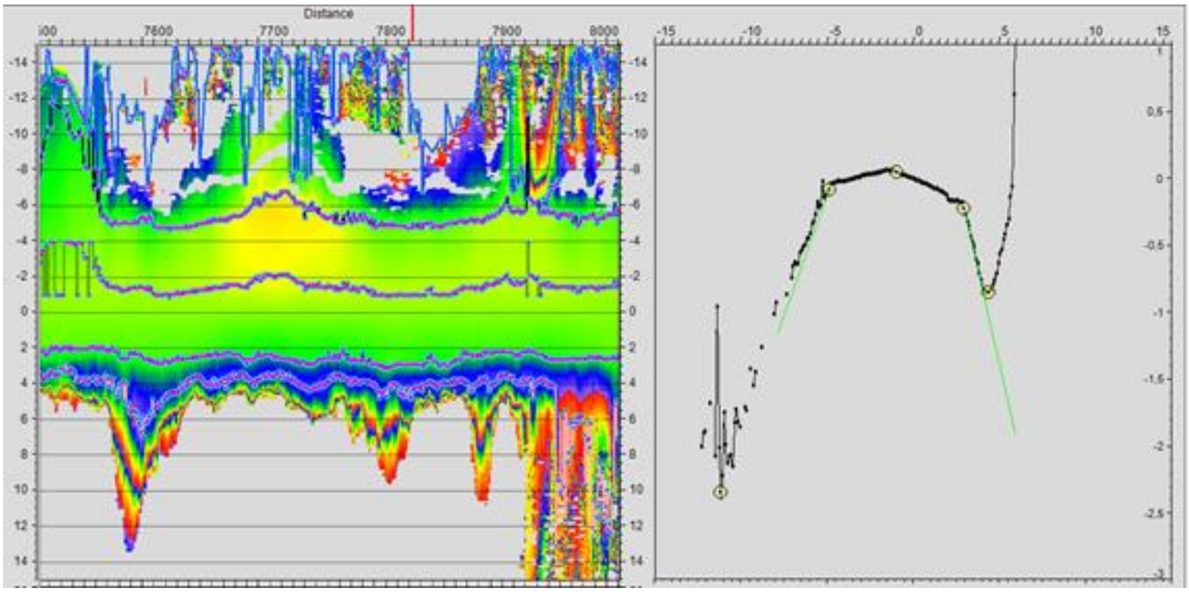


__Figure 6__. Screenshot from the Road Doctor software. Right side of the figure presents cross-section of road. Left side of the figure presents colored road elevation seen from the top to down. Automatically detected main components of cross section can be seen on right side (yellow circles). Detected angle of inner side slope is shown with green line.

4.2 Rutting

After reviewing of this test section, it was decided that most reliable rutting results can be achieved by digitizing road markings. The width of the lane is changing in curves and driving path is difficult to keep same between surveys. Figure 7 shows, how 3.2m wide “virtual measurement bar” overlaps the opposite lane.

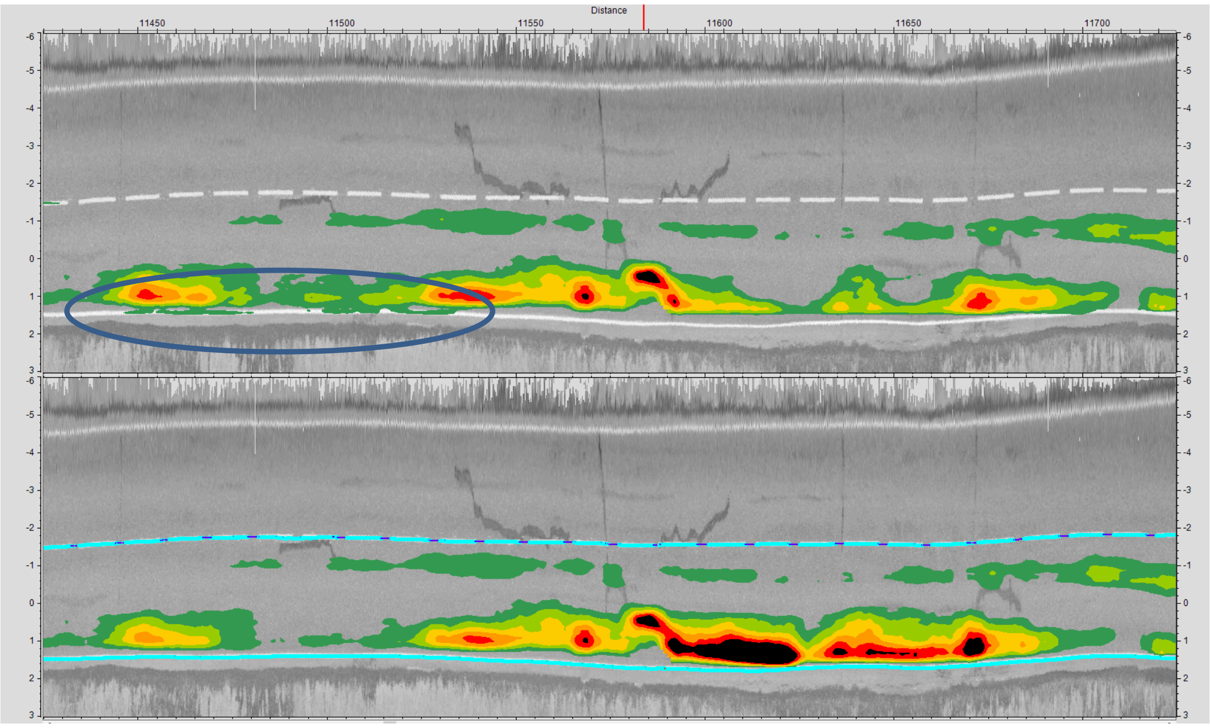


Figure 7. *Screenshot from the Road Doctor Software. In the upper window the rutting is less reliable because of constant width is spreading outside the carriageway. Lower window shows the benefit of digitizing the paint markings and calculating the ruts from actual road area.*

Rutting is calculated from point cloud data by generating 1m x 0.1m grid for specified calculation area. Road Doctor software calculates average heights from laser scanner for each cell of grid. Rutting is calculated from this grid using so called wire method. In Road Doctor, it is possible to use also bar, water, line to line methods or linear regression. In this section, rutting is calculated from painting to painting without subtracting width of paintings out (fig. 8). When road paintings are done using thermoplastic or epoxy, their height (0-3mm) causes errors to the rutting values and therefore the calculation area is moved from top of the marking.

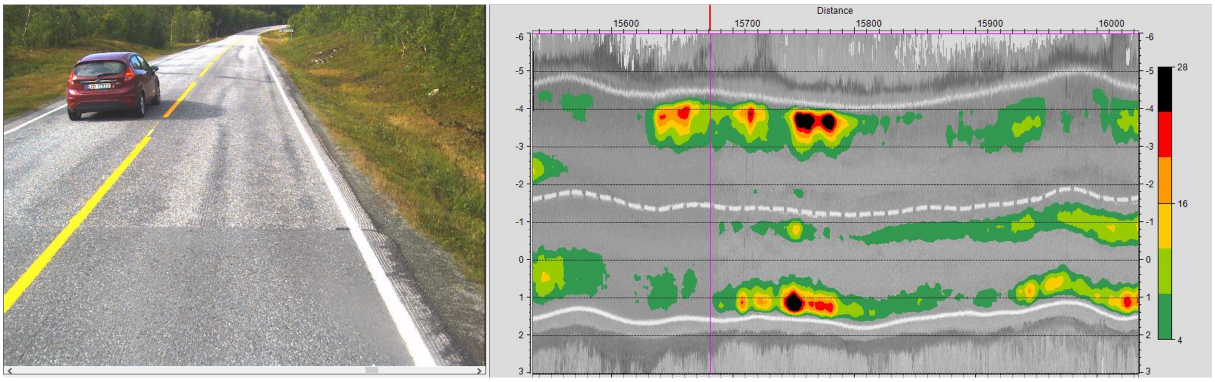


Figure 8. *Screenshot from the Road Doctor software. "Rutting map" presented over the point cloud surface. Rutting is calculated using wire method from the centerline to the edge road painting. Calculation area follows painting lines.*

Roadscanners uses visual “rutting map” as basic presentation of rutting values. Visual rutting map has many advantages compared to maximum rutting drawn as line diagram or excel table. This type of presentation directly indicates possible reason for rutting. Narrow. Straight ruts indicate typically wearing caused by studded tires or very high amount of traffic (erosion). Wider ruts, especially if located on the edge of road indicates problems with bearing capacity (heavy trucks) and weak road structures. From this visual presentation of rutting, it is possible to export rutting parameters to the table with given averaging.

4.3 Roughness

It is possible to define roughness from RDSV surveys in 2 ways (fig. 9). First, the accelerometer data can be used and when measuring GPR with horn antenna, the antenna elevation data can be used. The latter is based on determining the antenna height compared to the road surface. Naturally this is affected by characteristics of the vehicle and antenna mounting, but after several years of monitoring and even using different vehicles and setups, the results are very reliable and repeatable. This result is achieved as a side product of GPR data processing and therefore requires very little effort.

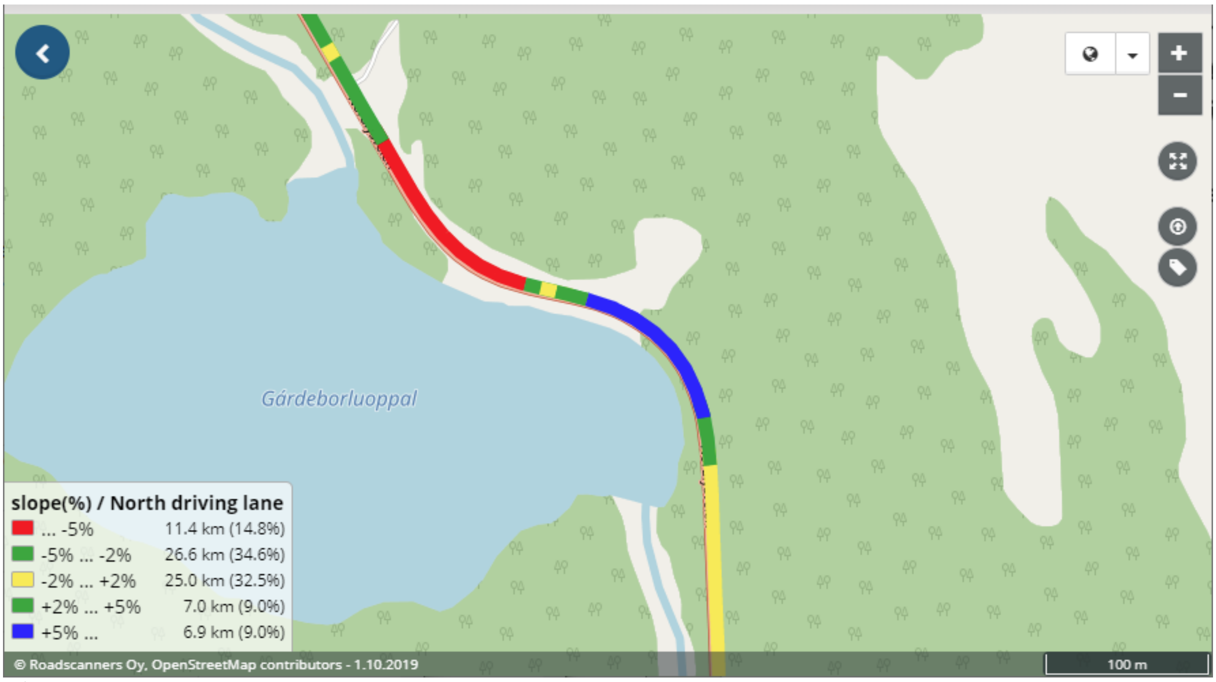
For more sophisticated roughness measurement, the accelerometer is used. Accelerometer based IRI is described as “Class 3 device” in commonly used World Bank’s classification of Road roughness measurement devices. Accelerometer doesn’t measure directly longitudinal profile of road surface, but profile can be calculated using accelerometer outputs. Accelerometer based IRI is called also as “Response-Type Road Roughness Measurement System”.

Location 18550,73m WE=721022,83m SN=7692264,12 Z=272,75m D 2572,79m

Figure 9*. Screenshot from roughness data. Antenna elevation on top and accelerometer based IRI value at the bottom.*

4.4 Cross fall

Cross fall is also calculated from point cloud data. There are several options how to calculate and which area is used for calculation. Most straight forward method is to select 1.6m wide area from both left and right of the laser scanner. Varying driving path will cause error if two results are compared. In this project, cross fall is calculated using linear regression line starting from centerline and ending to the edge road painting. Crossfall is reported as percentage, minus values in normal two-sided cross fall and plus values in curve in situation of one-sided cross fall (fig. 10). Point cloud filtering and processing options are used as in rutting calculation.



slope(%) / North driving lane

🟥	... -5%	11.4 km (14.8%)
🟩	-5% ... -2%	26.6 km (34.6%)
🟨	-2% ... +2%	25.0 km (32.5%)
🟩	+2% ... +5%	7.0 km (9.0%)
🟦	+5% ...	6.9 km (9.0%)

© Roadscanners Oy, OpenStreetMap contributors - 1.10.2019

***Figure 10**. Screenshot from the Road Data Center. Lane 1 crossfall classified and colored by its value.*

4.5 Road & carriageway width

To calculate width of the road or carriageway, user needs to either digitize road paintings or define shoulders from the cross section. Figure 11 shows how widths are defined. If pavement and unbound shoulder after the edge painting is constant, easy and reliable road width can be got by adding constant value to the carriage way width. In this project, road shoulders were detected using Road Doctor’s automatic routines and distance between shoulders was reported as road width. Carriageway width is distance between road edge paintings.

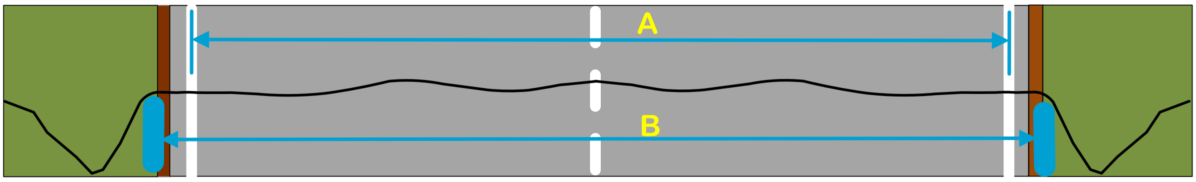


***Figure 11**. Measuring principles of road (B) and carriageway (A) width calculation.*

4.6 Side slopes

Detecting angle of inner side slope is optional parameter in automated detection cross section parameters. Automatic filtering procedures will be used for point cloud before detection to minimize effect of vegetation and to remove obstacles like rails and traffic signs from the data (Figure 12).

Figure 12. *Cross sections from point clouds processed in two ways: Red line is drawn from the point cloud filtered so that rails and signs are removed, and effect of vegetation minimized. Black line is drawn from unfiltered point cloud showing all points.*

There are two different parameters from side slope. First is directly calculated from edge to ditch bottom. The second parameter ("Q") is more accurate, because it is fitted to the actual shape of the slope. Figure 13 gives a good idea of the difference.

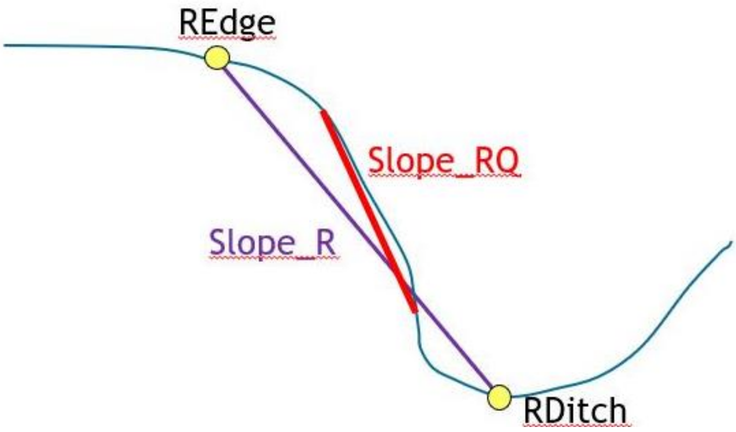


Figure 13. Side slope parameters used in laser scanner processing.

4.7 GPR layer thicknesses

The layer thicknesses included interpretation of bound layer bottom, base course, other unbound layer interfaces, overall road structure thickness, embankment and estimation of subgrade quality (notes for peat and bedrock). The results are provided as Road Doctor -project but also excel-table.

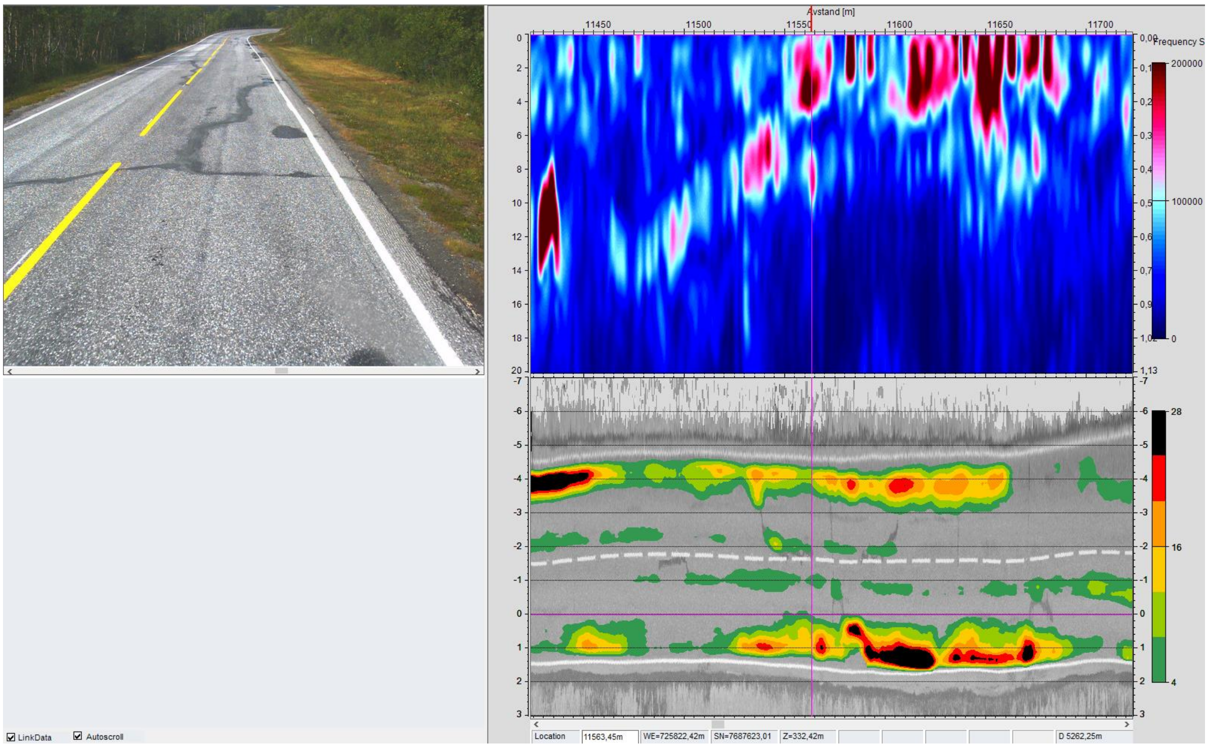
Data quality was high, and interpretation was easy in terms of following interfaces. Identifying layers was not always easy, but drill cores from carefully chosen locations helped the work.

The results will be delivered after the drill core verification.

5 Additional parameters

5.1 Moisture mapping with GPR

GPR is sensitive to changes in moisture in the road structure. This can be used to estimate moisture conditions in the structure by analysis of frequencies in the signal. It is vital for road strength that the structures are dry. The moisture data analyzed from GPR can be used to evaluate the drainage condition directly from road structure. It also gives indication if there are moisture susceptible materials in the structure (high fines content). In figure 14 the moisture analysis is shown in the same screen with rut map. It is clear to see that there are problems in drainage at the location. There are also damages in the road surface and poor ditch depths.



Location 11563,45m WE=725822,42m SN=7687623,01 Z=332,42m D 5262,25m

Figure 14. *Moisture analysis (GPR) on the top. The darker red the colour, the higher the relative moisture content. Rut map below; black colour is at least 28 mm deep rut.*

5.2 Verge, edge drop

Verges are a major problem on some road sections because they prevent the road from drying. They are also a hazard to road users because pooling is more likely during and after rain. The RDSV together with Road Doctor can be used to locate verges on the road. Example is shown in figure 15.

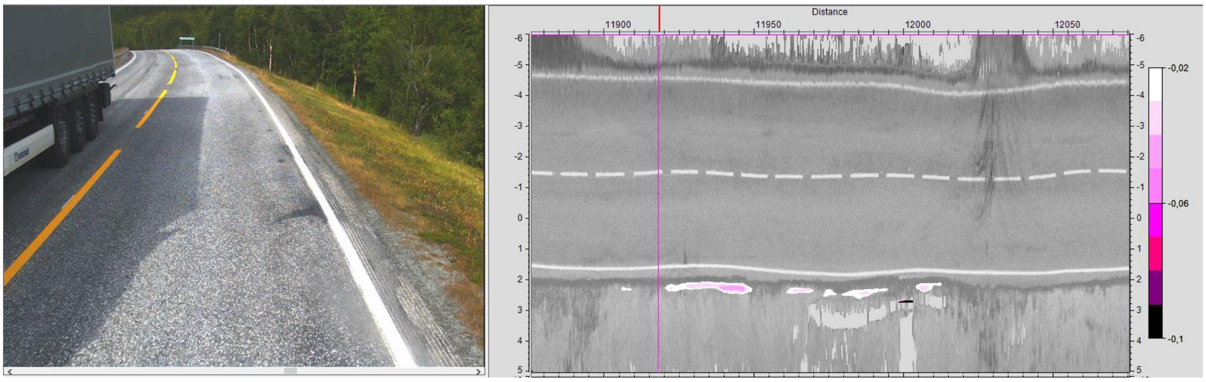


__Figure 15__. Verge on road E8. This road had no problems with verges and at this location the verge is on the outer curve and not an actual problem.

Edge drop is widely spoken opposite to verge. It means that the pavement is significantly higher than the unbound shoulder (gravel). It is a hazard to road users, because it can create unexpected change in the driving direction when the vehicle is just slightly off from the road pavement. It is even more severe for motor cyclists and cyclists. For pavement it is a problem because the pavement edge without support is prone to damage and edges can break. On local roads it is possibly an increasing problem because of longer trucks are allowed and curves are tight – more erosion to the inner curve. This means also that water is standing in the edge drop – more problems to pavement and base course and eventually cracks. Example how edge drop is presented in Road Doctor integrated data view is shown in figure 16.

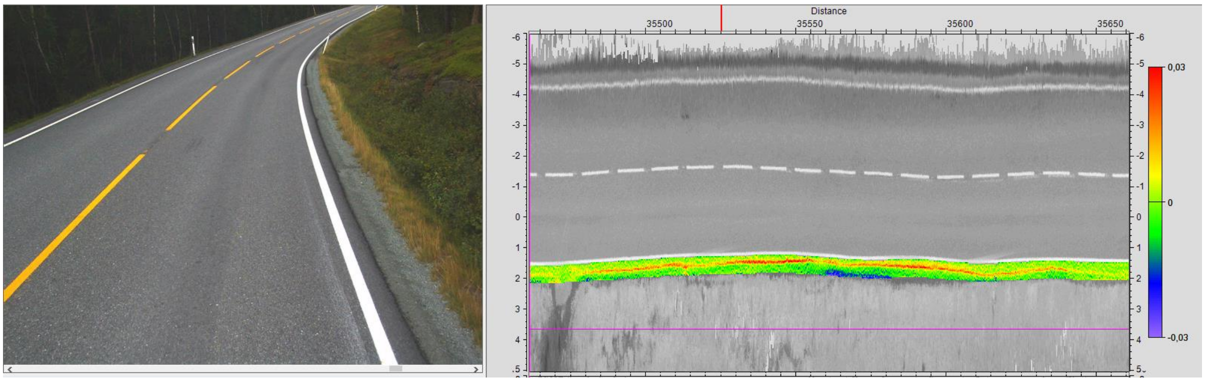
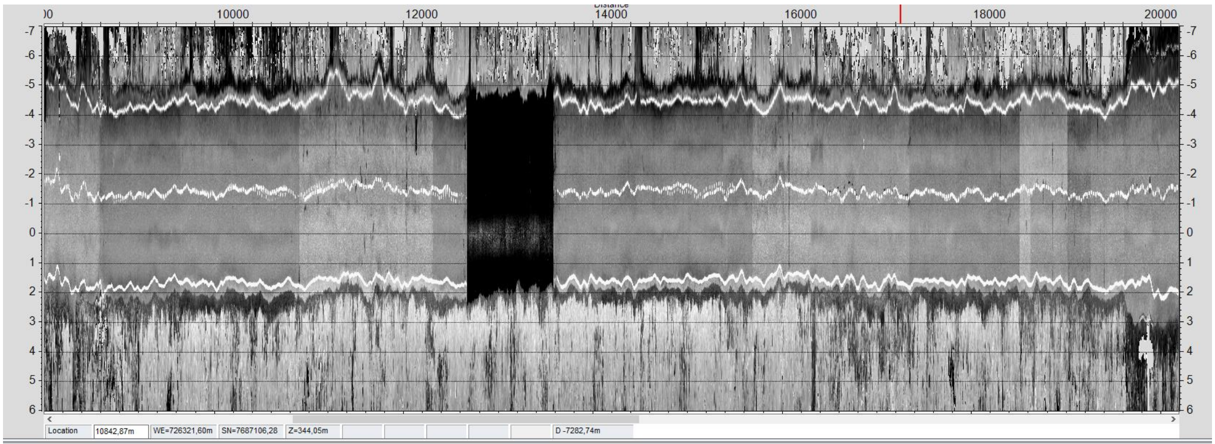


__Figure 16__. Edge drop. The colour moves towards red when the drop from pavement to the bottom of the drop increases.

5.3 Homogenous surface sections

The remission or reflectivity data from laser scanner can be used to present different pavement section areas or amount of patching. If remix operation is will be designed, it is good practice to plan sampling for each paved section. Figure 17 presents Road Doctor view having 12 km long profile of point cloud data. This very long “top-down” view is one good example of “road specific” tools in Road Doctor. It’s common that point cloud is presented as “virtual world” which can be rotated and zoomed but impossible to see 12km in one view using standard laptop.

***Figure 17**. From remission map of laser scanner, the homogenous sections and patching can be easily located. Also, the area can be calculated quickly and in a reliable way. From this image it is also easy to see the changes in the driving path.*

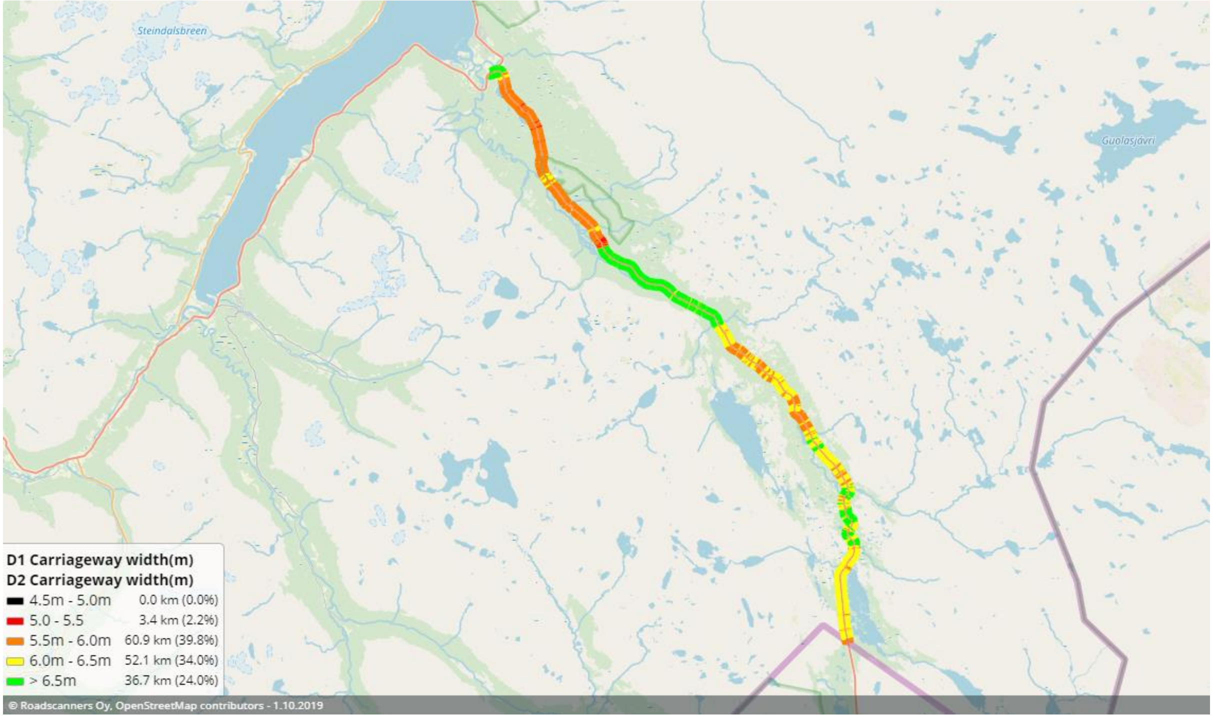


Location 10842,87m WE=726321,60m SN=7687106,28 Z=344,05m D -7282,74m

Parameters in the excel-table

RUT1_left(mm)	- maximum rut depth in left (inner) wheel path
RUT1_right(mm)	- maximum rut depth in right (outer) wheel path
RUT1_ridge(mm)	- ridge height between the ruts (wire method)
RUT1_SEPA(m)	– distance between left and right max rut
Crossfall(%)	- crossfall in percent (normal value for two-sided - 3-5%)
Carriageway width(m)	- width between the road paint line
Road width(m)	- road width including unpaved shoulder
Ditch depth(m)	- ditch depth from road shoulder to bottom of the ditch
Side slope(1:x)	- side slope to ditch (values 1:1.5 to 1:3 in normal conditions)
Pitch_IRI	- IRI value calculated from accelerometer data
MDI	- Moisture Damage Index from GPR data

Appendix 1. Carriageway width

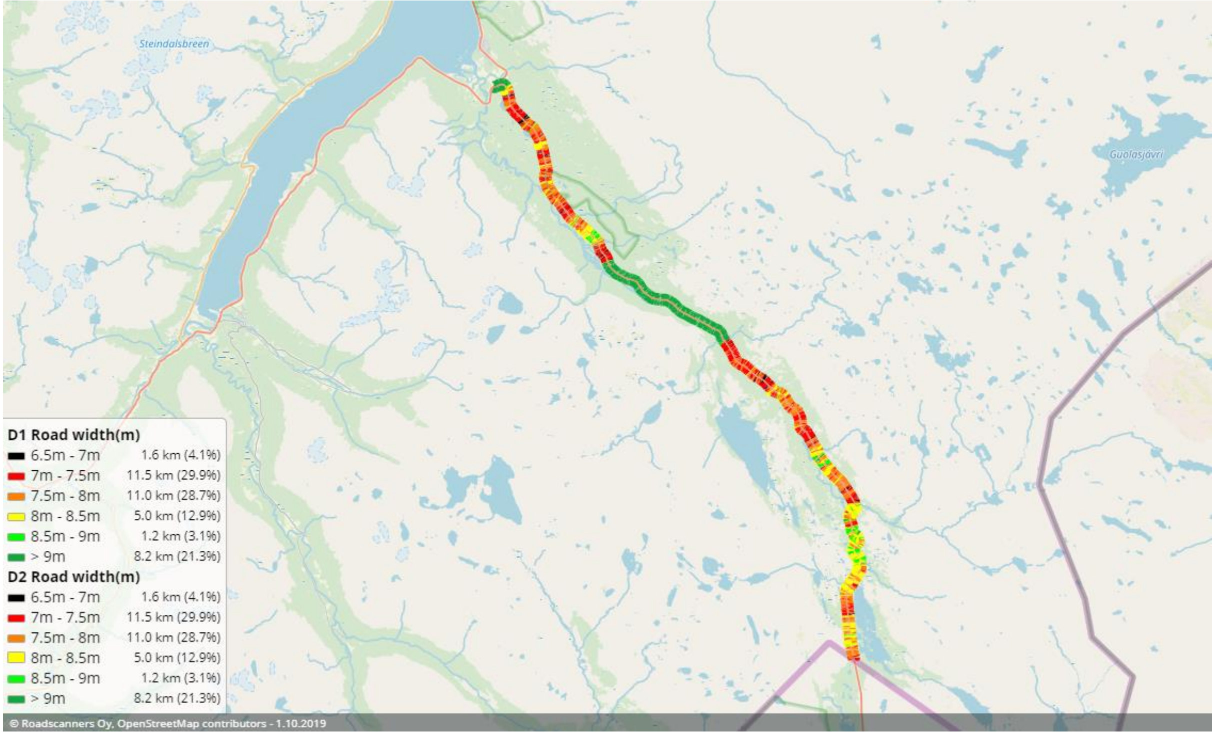


Appendix 2. Cross fall

Appendix 3. Ditch depth

Appendix 4. Moisture Damage Index

Appendix 5. Road width



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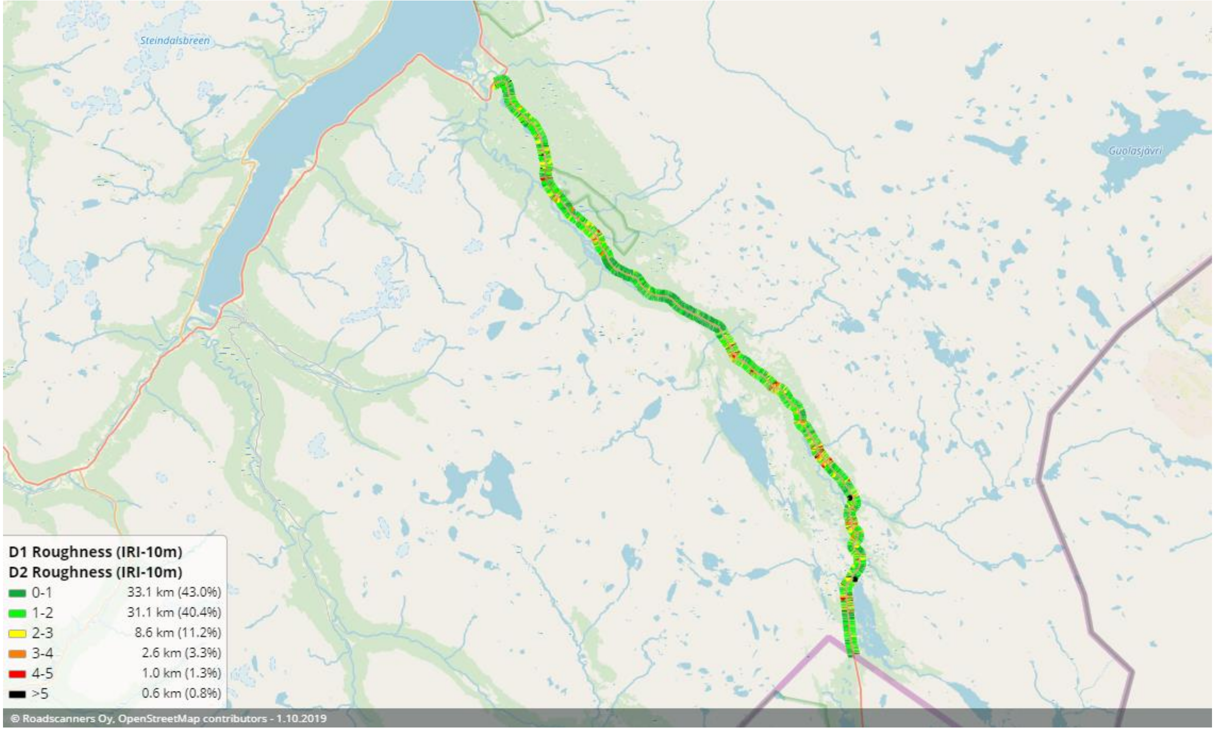
Appendix 6. Roughness



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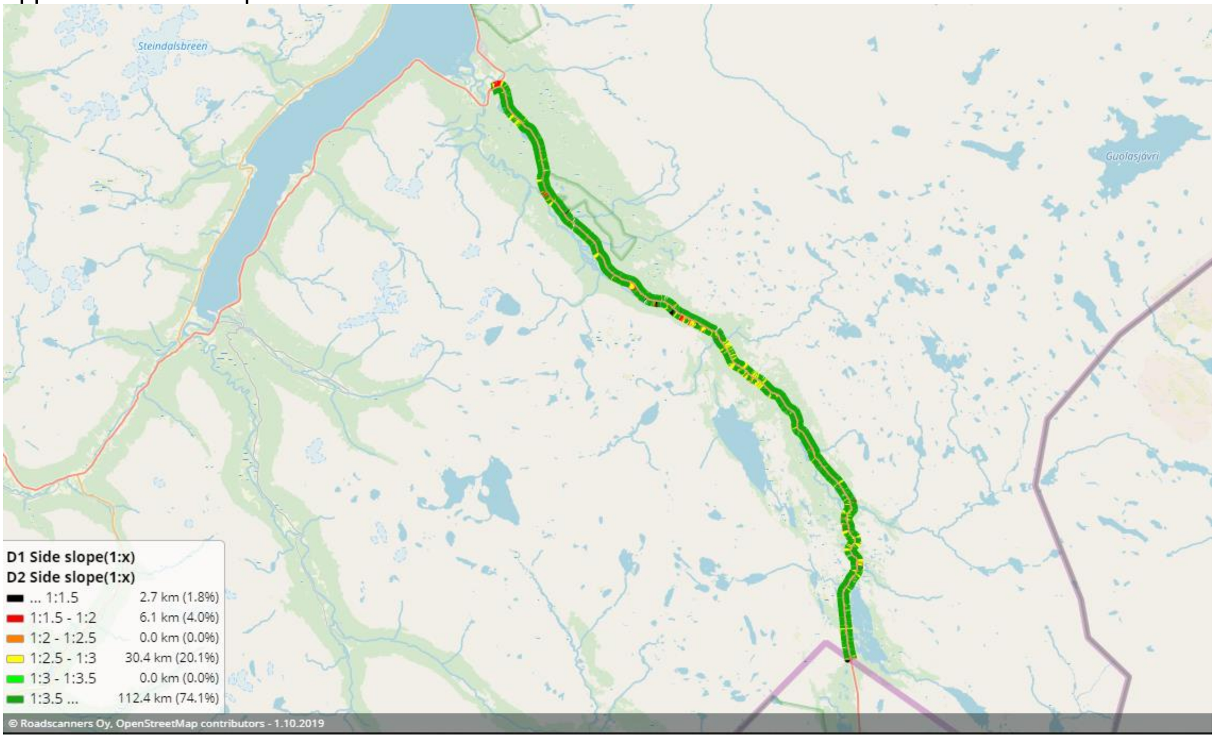
Appendix 7. Rutting

Appendix 8. Side slope



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BEYOND
THE
SURFACE

RAMBOLL

Attachment 2

TRANSPORT

Doreen Siebert
Bakløkk Leif Jørgen

Norwegian Public Roads Administration
Abels gate 5, TRONDHEIM

>As agreed

Date 30/09/2019

Pavement measurements at E8 in Troms Norway – Ramboll RST

This report summarises the measurement performed at E8 in Troms (Nordkjosbotn/Skibotn).

The basic structure to present the results is:

- The results are delivered as MS Excel files.
- The starting point for measurements is marked as 0.
- Direction for measurements is marked as 1 or 2.
- Co-ordinates are in Euref89 Zone 34V Height model: NN1954
- The results are delivered as 20 m results.
- The dates for measurements were 20 and 21 August 2019.

Some key values from the delivered data:

- Direction 1 – from 0 to 38480 m
- Direction 1 - 1924 pcs. of 20 m rut result
- Direction 2 - – from 0 to 38560 m
- Direction 2 – 1928 pcs. of 20 m rut result

The results (both directions) are presented in attached file "*E8_RambollRST_092019_results20m.xlsx*"

The 1 m results are presented in attached files:

- Direction 1: *E8_RambollRST_092019_1m_direction1.xlsx*
- Direction 2: *E8_RambollRST_092019_1m_direction2.xlsx*

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Ref Vegvesen E8 Borealis

Condition parameters

Rutting/transverse unevenness:

The rutting results are calculated with taut *wire method* “An imaginary wire is stretched across the 4m transverse profile enveloping the high points and fixed at either end”.

The width of the transversal profile is limited according to the lane markings or to maximum width of 3.2 m.

The results are provided for:

- maximum rut depth (mm)

Some key values from the delivered data:

- Direction 1 - average 3.92 mm
- Direction 2 – average 4.25 mm

Other parameters can be calculated, like rutting width, rutting area or edge drop, although this measurement object was in good condition and these parameters are not useful on new pavement.

Longitudinal unevenness/surface characterization:

IRI-value is calculated according to the “International World Banks specification ”Guidelines for Conducting and Calibrating Road Roughness Measurements”. World Bank Technical Paper Number 46” method, so called “Quarter Car simulator” and definitions according to the Swedish National Road Administration document: TDOK 2014:0003, Vägytemätning Mätstorheter, Chapter 2.1”.

The results are provided for:

- left (iri_left) wheel path (mm/m)
- right (iri_right) wheel path (mm/m).

Some key values from the delivered data

- Direction 1 – left wheel path average 1.26 mm/m
- Direction 1 – right wheel path average 1.45 mm/m
- Direction 2 - left wheel path average 1.39 mm/m
- Direction 2 – right wheel path average 1.54 mm/m

MPD value(s), Mean Depth Profile

MPD values describe the texture of the pavement surface (macrotexture). The calculation method for MPD calculatin method is described at the document by the Swedish National Road Administration document: TDOK 2014:0003, Vägytemätning Mätstorheter, Chapter 2.9.1”.

MPD is calculated for three longitudinal lines:

- MPD_left – left wheel path
- MPD_center – in the middle of lane
- MPD_right – right wheel path

Some key values from the delivered data:

- Direction 1 – MPD left / center / right, average 0.78 / 0.83 / 0.82
- Direction 2 – MPD left / center / right, average 0.78 / 0.82 / 0.78

Slope

Slope is calculated from the same transversal profiles as the other results. The method for slope calculation is the “regression slope”, described at the document by the Swedish National Road Administration document: TDOK 2014:0003, Vägytemätning Mätstorheter, Chapter 2.6”.

The results are provided for:

- slope (%)

Surface damages: (cracks, crocodile cracking, inhomogeneity)

The delivered parameters to describe the surface damages are:

- Cracks length per 20 m (and per 1m)
- Crack area per 20 m (and per 1 m)

Crack area is calculated based on 100 x 100 mm grid and the square affected by identified crack is calculated as cracked area. The calculation is easily modified, and it is recommendable that the different crack variable definitions, like the position and severity, will be defined with the Client.

Some key values from the delivered data:

- Direction 1 – 42 % of 20m sections were crack free
- Direction 1 - average detected crack length on cracked 20m section is 5.5 m
- Direction 2 – 40 % of 20m sections were crack free
- Direction 2 - average detected crack length on cracked 20m section is 6.0 m

Figures 1 and 2 present crack images from the LCMS system. The details of from crack detection is much better than visual detection from front view images can provide.

Figure 1. Front view image and LCMS overlay from direction 2, location 27280

Figure 2. Front view image and LCMS overlay from direction 2, location 31 420

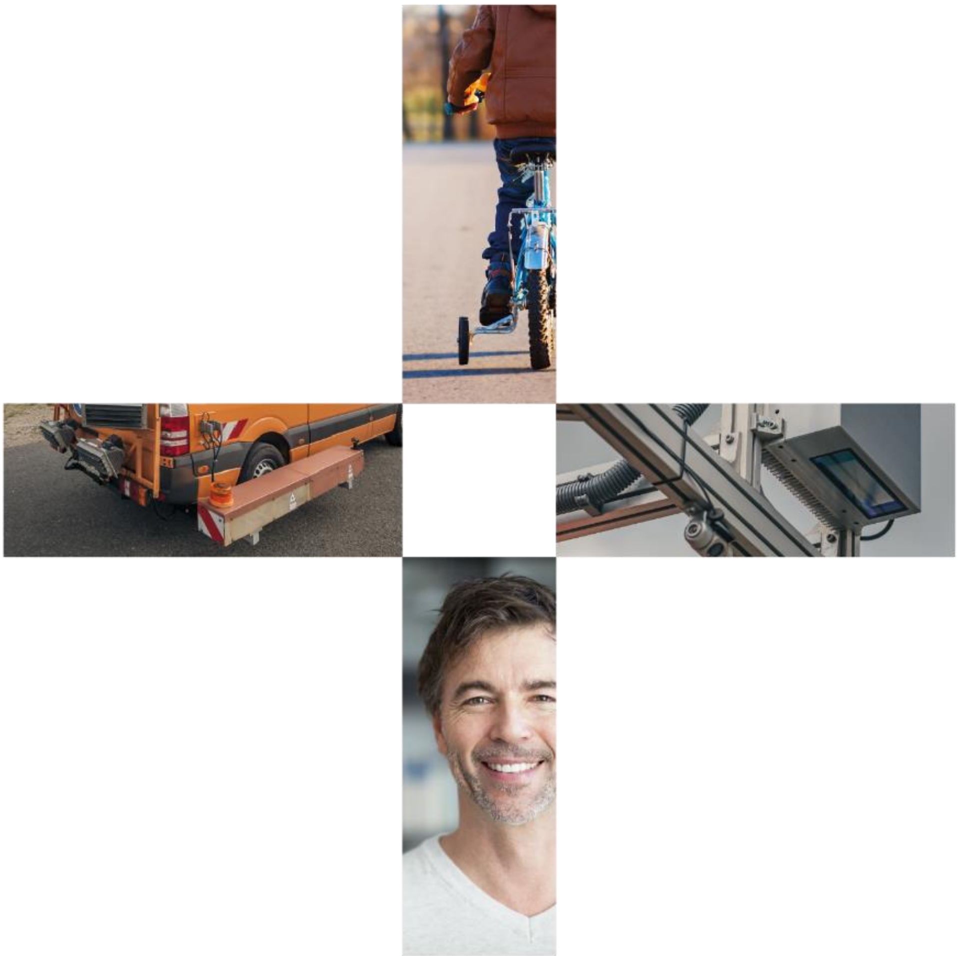
Attachment 3

Statens vegvesen
Norwegian Public Roads Administration

Report

P 18-325

3D road condition monitoring on the arctic intelligent transport test ecosystem Borealis on E8



Dresden, 07.11.2019

GINGER
LEHMANN+PARTNER

CONTENTS

1 General Scope

On the E8 between the Finnish border and the town of Skibotn the arctic intelligent transport test ecosystem Borealis has been established. This test track has a length of round about 40 kilometres.

The aim of the project for the Norwegian Public Roads Administration is to compare different systems for condition detection with their currently used system and to finally evaluate pros and cons of the different systems available.

LEHMANN+PARTNER participated in the project with its mobile mapping system I.R.I.S. 13. The I.R.I.S. 13 is equipped with a high-precision positioning system, two Fraunhofer LiDAR instruments and a camera system. The data, which can be recorded with I.R.I.S. 13, is normally used for 2D and 3D documentation of the measuring section as well as for condition monitoring and object detection. The project focus was:

- Transversal evenness (e.g. rutting)
- Longitudinal evenness (e.g. IRI)
- Surface damages (e.g. cracks)
- Corridor analysis

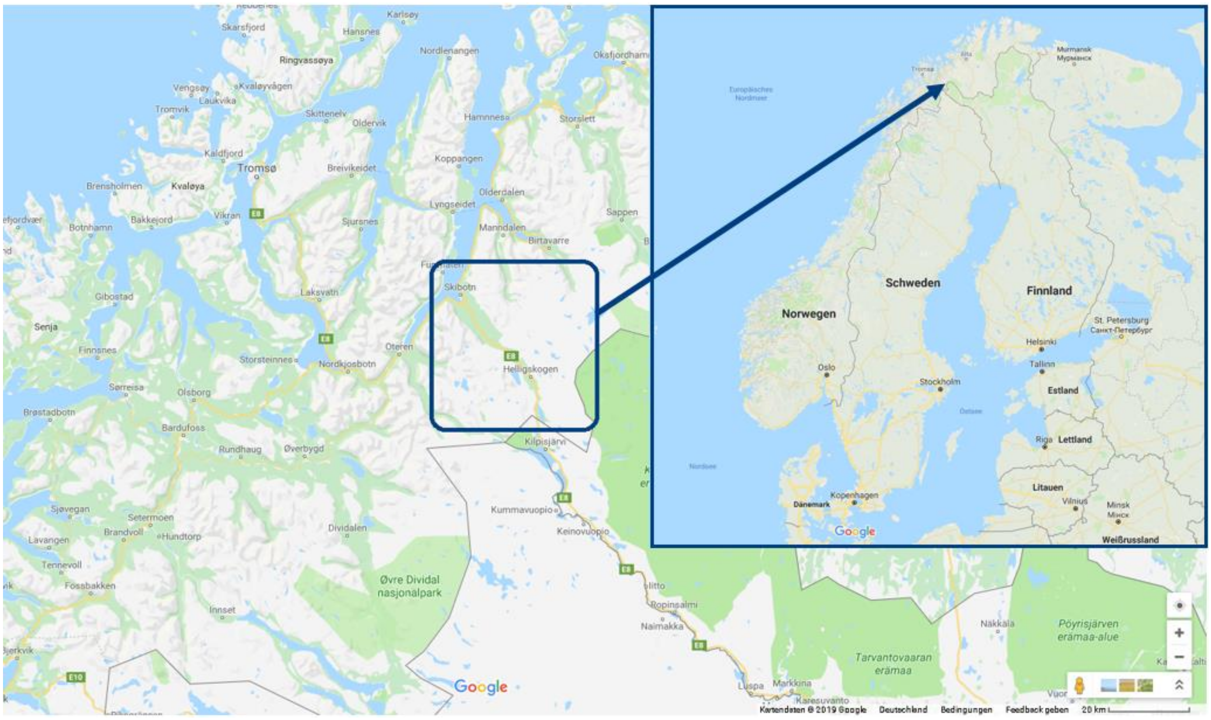


Figure 1: Location of the Borealis project on E8.

2 Data acquisition

The measurements referred to in this report took place on 2019-08-22. In detail, the following two test tracks were measured:

- Finnland border to Skibotn (11:53 to 12:20): presented in this report
- Skibotn to border Finnland (12:33 to 13:20): not presented in this report

It must be mentioned that there was rain during the night from 2019-08-21 to 2019-08-22. The surface condition was mostly dry in this timeslot. Nevertheless, some cracks were still soaked with moisture.

Figure 2: Example image from the measurement on E8 on 2019-08-22, noon.

The statistics of Skibotn weather observation site suggests an average temperature of 14°C (minimum temperature 9°C and maximum temperature 14.5°C). Precipitation was 1.5 mm (measured at 7AM for the past 24 hours). For more climate data see Table 1.

Table 1: Statistics of Skibotn weather observation site (source: https://www.yr.no/place/Norway/Troms/Storfjord/Skibotn_observation_site/statistics.html).

Date	Min. Temp. [°C]	Temp. at 2 PM [°C]	Max. Temp. [°C]	Precipitation [mm]
2019-08-20	12.4	17.4	18.8	13.0
2019-08-21	6.5	17.8	18.0	0.1
2019-08-22	9.0	no value	14.5	1.5

3 Hardware

3.1 Mobile Mapping System I.R.I.S 13

The mobile mapping system I.R.I.S 13 is a kinematic measuring system for pavement condition survey and for collecting roads environment at traffic speed. The main components are:

- Inertial positioning system APPLANIX POS LV 420
- Pavement Profile Scanner +: LiDAR sensor from Fraunhofer IPM Germany
- Clearance Profile Scanner: LiDAR sensor from Fraunhofer IPM Germany
- 4 high resolution single frame cameras for the photogrammetric acquisition of road environment

Figure 3: Mobile Mapping System I.R.I.S 13 with an inertial positioning system, several cameras and LiDAR sensors mounted on the roof rack. This image has been taken during the measurement on 22nd August 2019 on E8.

3.2 Inertial Positioning System

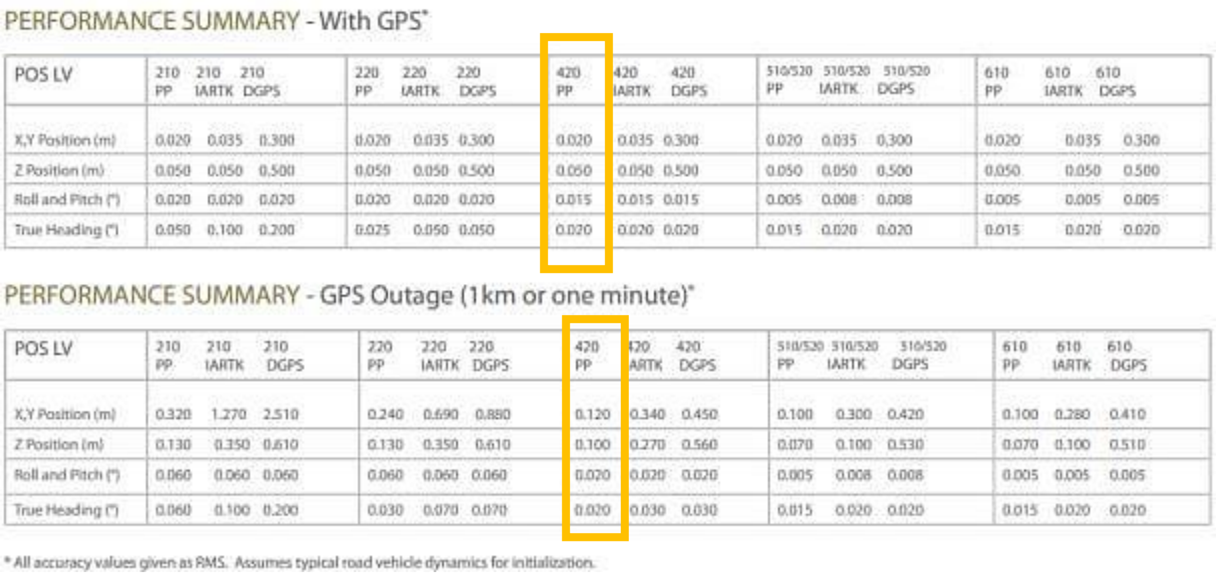
The position and orientation system for land vehicles (POS LV) that is shown in Figure 4 is designed to provide a full navigation (position and orientation) solution for land vehicles engaged in road surveying and mapping, or road profiling with lasers. These applications require continuous position and orientation information while operating in areas where problematic GPS reception would be encountered. POS LV utilizes IARTK (Inertially-Aided Real-Time Kinematic) technology, and is a compact, fully integrated, turnkey position and orientation system, utilizing IARTK to generate stable, reliable and repeatable positioning solutions for land-based vehicle applications.

Figure 4: Applanix IMU and central PC.

Designed to operate under the most difficult GPS conditions that can be found, POS LV enables accurate positioning for road geometry, pavement inspection, GIS database and asset management, road surveying, and vehicle dynamics.
For reliable use, as well under critical GPS receiving signal conditions Vectra recommends the use of the system POS together with the respective post-processing software module. This is the configuration that gives accurate enough positioning results to be linked with the point data stream provided by the laser scanner. Optional post-processing software can be recommended to compute an optimal blended position solution and orientation solution from the inertial, GPS and other data sources (DMI), especially suited for 3D- modelling. The post-processing tool employs forwards and reverse processing, enhanced error modelling, multiple GPS base-station processing and enhanced gravity modelling.
The POS LV tightly coupled inertial GNSS system continuously verifies available raw GNSS data as it arrives to make certain that only valid signals become a part of the positioning solution while also presenting a continuous position and orientation solution throughout a total or partial GNSS outage. POS LV420 support precise heading with GAMS.
The more accurate the heading determination at the start of an outage, the longer a system can stay on target. The GNSS Azimuth Measurement Subsystem (GAMS) – together with the LV 420 - relies on two GNSS receivers and two antennas affixed to the vehicle two meters apart. POS LV then computes a moving baseline RTK solution that uses GNSS phase measurements to get a precise determination of one antenna’s position relative to the other. This approach helps eliminate inertial drift errors that are typically produced in single antenna systems when vehicle progress stops. GAMS make it possible to determine the vehicle’s heading very accurately regardless of speed, resulting in the best possible heading accuracy and the best performance in any environment.
By combining easy sensor system integration (such as the laser) with time-tagged position and orientation data logged at up to 200 Hz, POS LV sustains highly consistent a reliable data capture. POS LV filters raw GNSS so that only well-founded signals are incorporated into the results. A DMI, Distance Measurement Indicator (odometer) is inevitable prerequisite for stabilizing the IARTK system and for retrieving an optimal blended post-processing solution.

The POSPac™ MMS (Mobile Mapping Suite) post-processing software which comes with the positioning hardware is designed to maximize the accuracy potential of POS LV systems. From project planning through to completion, POSPac MMS software simplifies mission scheduling, utilizes smart time-saving features including pre-planning and batch processing resources, and offers customizable options with powerful quality control and data analysis tools. We will always use post-processing for any collected data.

Basis for reliable geo-rectification of the survey photos is the kinematic positioning system. The POS-LV positioning system is ideally suited for including base station data in the post-processing whose coordinates come in other datum than WGS84.



PERFORMANCE SUMMARY - With GPS*

POS LV	210 PP	210 IARTK	210 DGPS	220 PP	220 IARTK	220 DGPS	420 PP	420 IARTK	420 DGPS	510/520 PP	510/520 IARTK	510/520 DGPS	610 PP	610 IARTK	610 DGPS
X,Y Position (m)	0.020	0.035	0.300	0.020	0.035	0.300	0.020	0.035	0.300	0.020	0.035	0.300	0.020	0.035	0.300
Z Position (m)	0.050	0.050	0.500	0.050	0.050	0.500	0.050	0.050	0.500	0.050	0.050	0.500	0.050	0.050	0.500
Roll and Pitch (°)	0.020	0.020	0.020	0.020	0.020	0.020	0.015	0.015	0.015	0.005	0.008	0.008	0.005	0.005	0.005
True Heading (°)	0.050	0.100	0.200	0.025	0.050	0.050	0.020	0.020	0.020	0.015	0.020	0.020	0.015	0.020	0.020

PERFORMANCE SUMMARY - GPS Outage (1km or one minute)*

POS LV	210 PP	210 IARTK	210 DGPS	220 PP	220 IARTK	220 DGPS	420 PP	420 ARTK	420 DGPS	510/520 PP	510/520 IARTK	510/520 DGPS	610 PP	610 IARTK	610 DGPS
X,Y Position (m)	0.320	1.270	2.510	0.240	0.690	0.880	0.120	0.340	0.450	0.100	0.300	0.420	0.100	0.280	0.410
Z Position (m)	0.130	0.350	0.610	0.130	0.350	0.610	0.100	0.270	0.560	0.070	0.100	0.530	0.070	0.100	0.510
Roll and Pitch (°)	0.060	0.060	0.060	0.060	0.060	0.060	0.020	0.020	0.020	0.005	0.008	0.008	0.005	0.005	0.005
True Heading (°)	0.060	0.100	0.200	0.030	0.070	0.070	0.020	0.030	0.030	0.015	0.020	0.020	0.015	0.020	0.020

* All accuracy values given as RMS. Assumes typical road vehicle dynamics for initialization.

Figure 5: Applanix POS LV performance specs.

During the measurement, the positioning software records GPS positions from the inertial system for every picture. Later after the survey all recorded positioning data is being processed to increase the accuracy by recalculation using differential corrections from base stations network. Special software connects pictures with correspondent position to have most accurate coordinates of every frame. Beside geographical coordinates every picture gets all parameters describing position of the car while taking the frame (heading, pitch, roll) which are very important in algorithm for taking measurements on pictures.

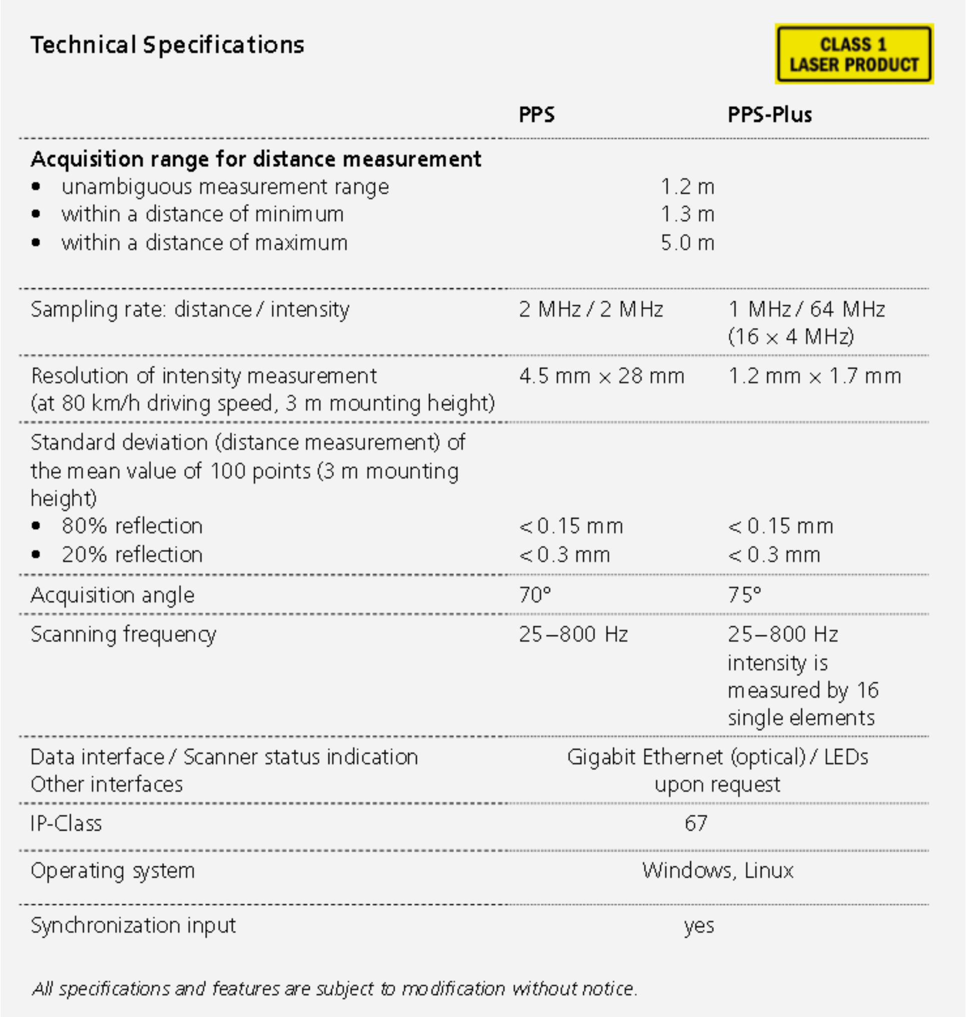
3.3 *LiDAR sensors*

3.3.1 Pavement Profile Scanner +

For recording the pavements surface, LEHMANN+PARTNER uses the Fraunhofer Pavement Profile Scanner PPS +. The PPS + device has two integrated laser sensors:

- 3D unit (also PPS unit)
- 2D unit (also PPS + unit)

The 3D unit measures geometric (X, Y, Z) and radiometric information (intensity) of the road surface. Whereas the 2D unit only measures radiometric information (intensity) but with a much finer resolution – so surface features can be identified down to the millimeter level. For technical details refer to Figure 6.



Technical Specifications

CLASS 1 LASER PRODUCT

	PPS	**PPS-Plus**
Acquisition range for distance measurement		
• unambiguous measurement range	1.2 m	
• within a distance of minimum	1.3 m	
• within a distance of maximum	5.0 m	
Sampling rate: distance / intensity	2 MHz / 2 MHz	1 MHz / 64 MHz (16 × 4 MHz)
Resolution of intensity measurement (at 80 km/h driving speed, 3 m mounting height)	4.5 mm × 28 mm	1.2 mm × 1.7 mm
Standard deviation (distance measurement) of the mean value of 100 points (3 m mounting height)		
• 80% reflection	< 0.15 mm	< 0.15 mm
• 20% reflection	< 0.3 mm	< 0.3 mm
Acquisition angle	70°	75°
Scanning frequency	25–800 Hz	25–800 Hz intensity is measured by 16 single elements
Data interface / Scanner status indication	Gigabit Ethernet (optical) / LEDs	
Other interfaces	upon request	
IP-Class	67	
Operating system	Windows, Linux	
Synchronization input	yes	

All specifications and features are subject to modification without notice.

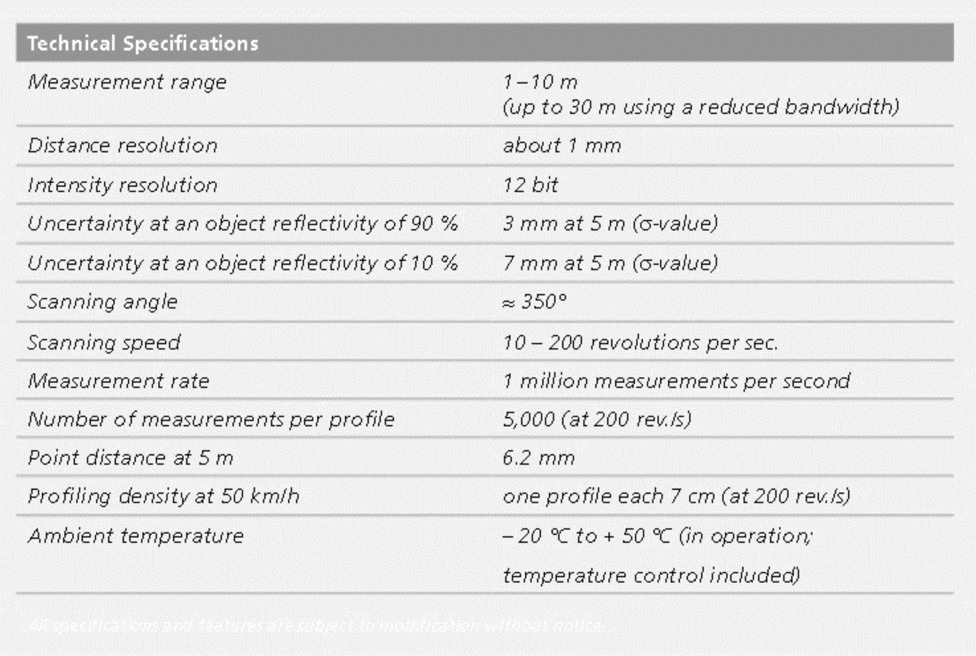
Figure 6: Technical specifications of the PPS+

3.3.2 Clearance Profile Scanner

For recording the corridor of the driven trajectory in 3D, LEHMANN+PARTNER uses the Fraunhofer Clearance Profile Scanner CPS. As a deflecting device, it has a rotating mirror and scans its surroundings in the form of a 2D profile. By moving the measuring platform, they successively complement each other to form a 3D scene. Other than the PPS +, the CPS device has only one laser sensor:

- 3D unit

The CPS 3D unit measures geometric (X, Y, Z) and radiometric information (intensity) of the road corridor.



Technical Specifications	
Measurement range	*1 – 10 m* *(up to 30 m using a reduced bandwidth)*
Distance resolution	*about 1 mm*
Intensity resolution	*12 bit*
Uncertainty at an object reflectivity of 90 %	*3 mm at 5 m (σ-value)*
Uncertainty at an object reflectivity of 10 %	*7 mm at 5 m (σ-value)*
Scanning angle	*≈ 350°*
Scanning speed	*10 – 200 revolutions per sec.*
Measurement rate	*1 million measurements per second*
Number of measurements per profile	*5,000 (at 200 rev./s)*
Point distance at 5 m	*6.2 mm*
Profiling density at 50 km/h	*one profile each 7 cm (at 200 rev./s)*
Ambient temperature	*– 20 °C to + 50 °C (in operation;* *temperature control included)*

All specifications and features are subject to modification without notice.

Figure 7: Technical specifications of the CPS

3.4 *Photogrammetrically calibrated single frame cameras*

During a measurement campaign pictures are taken of several cameras pointing into different directions (e.g. front, left/right, rear). All measuring cameras are calibrated, so that e. g. relative distances or absolute coordinates can be measured from the images. All pictures are in colour and high resolution. Each individual image has the information of an exact location assignment: GPS coordinate, camera direction, date taken etc. The images allow to evaluate the visible elements up to 8 meters to the right and left of the driving axis. Usually, this imagery is used to capture inventories as point/line/area-objects or surface damage characteristics of roadways and sidewalks. All the mentioned information that can be extracted from the imagery is precisely georeferenced. Therefor the results can easily be integrated in contemporary GIS software. The measurement sequences of the roof cameras can optionally be transferred in a desktop-based or a web-based viewer solution.

Figure 8 shows the LP-portal interface for a municipality. In the background there is a base map with all topographic information. On top of this, all project specific spatial data can be displayed. This data is listed as layers at the left margin of the interface (e.g. condition information, surface type information, network information). Using the main toolbar in the middle viewer and measurement tools can be activated. Images will appear based on the location that has been clicked in the map. Photogrammetric algorithms allow to take measurements inside the images (e.g. width of a lane).

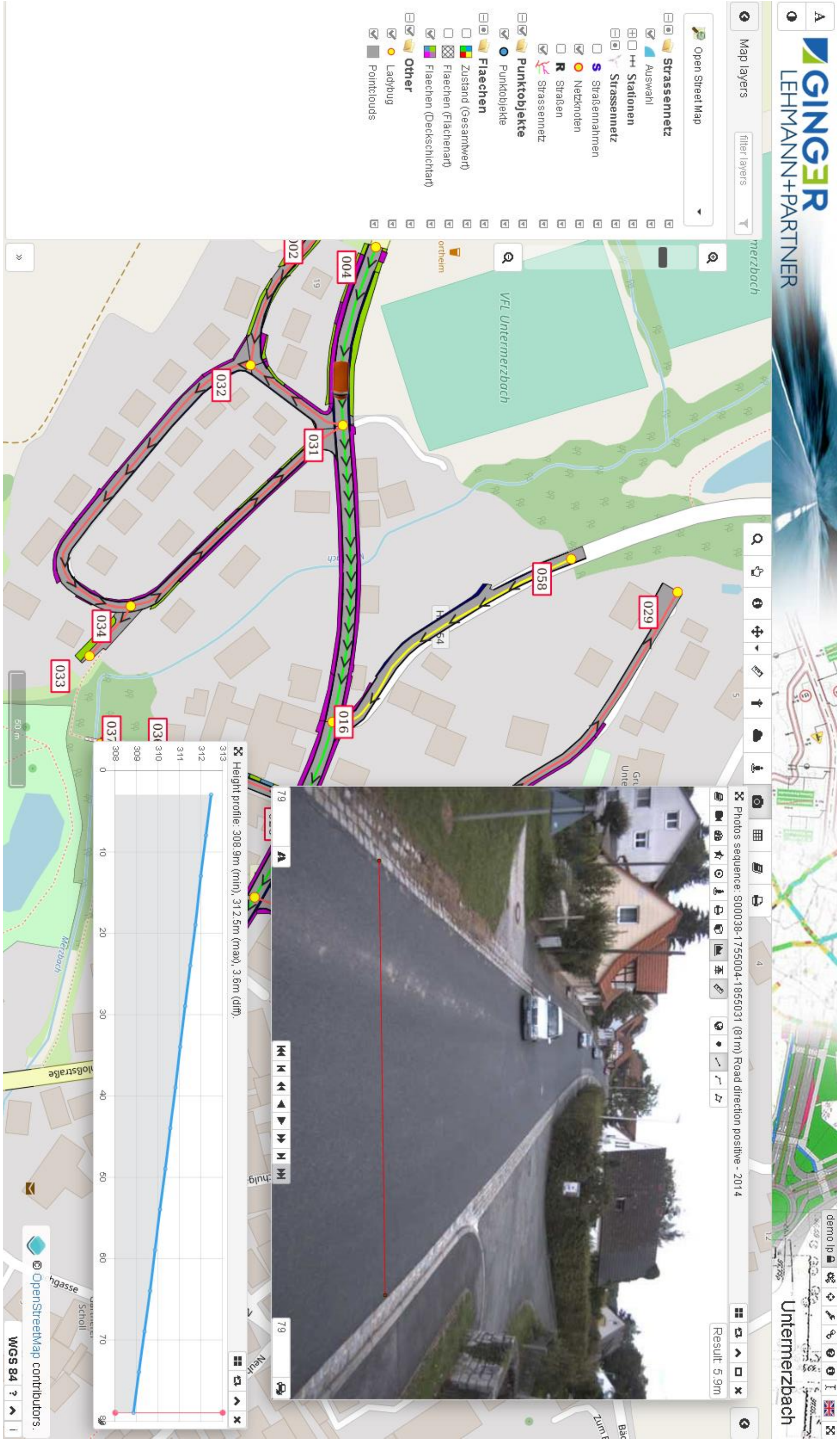


Figure 8: Example of the so-called LP-portal. This is a web-GIS solution for visualization of and interaction with all data recorded and analysed by LEHMANN+PARTNER. As an offline alternative we provide a free image viewer software that interacts with the free and open-source QGIS.

4 Data Processing: Summary of results

The recorded data were processed after completion of the measurements. The in-house post-processing focused on the following aspects:

- Transversal evenness
- Longitudinal evenness
- Surface damages
- Road corridor monitoring

For details refer to Table 2.

Table 2: Overview of the sensors used and the corresponding data products. The column final data hold just the relevant aspects for this project. This could be modified to fit country-specific needs.

Sensor	**Data product hierarchy**				**Application**
	raw data	**intermediate data**		**final data**	
Applanix POS LV	real time data	post-processed solution using e.g. Kalman filter		trajectory that quantifies all movements of the measuring platform	All sensors listed below are referenced to the trajectory
PPS +	3D point clouds	3D surface model	transversal profiles	rutting	Evenness evaluation
			longitudinal profiles	IRI, planograph simulation	
		2.5D surface model		georeferenced damage polygons	Surface damage evaluation
	surface images	damage grid		damaged area	
CPS	3D point clouds	GeoTIFF surface model		georeferenced object or/and surface polygons	3D Road corridor mapping
Cameras	RGB images	camera calibration files		image viewer with measuring tools / LP-portal	Picture documentation, Photogrammetric mapping

4.1 Post-processing of the trajectory

The trajectory is the movement path of the measuring vehicle. During the data acquisition the positioning solution is based on the real-time position data (GNSS, IMU, DMI). In a post-processing step the position quality of the real-time solution can be increased by factor of 10 to 100. To achieve precisely georeferenced data results the trajectory travelled is optimized using the post-processing software “POSPac MMS”. To further increase the accuracy, base stations can be used. For the actual measurements no reference stations were available. For this the positioning quality is only affected by the used sensors, the prevailing GPS conditions during the data acquisition and the implemented post-processing algorithms (e.g. Kalman filter). Figure 9 shows the GPS/GLONASS conditions.

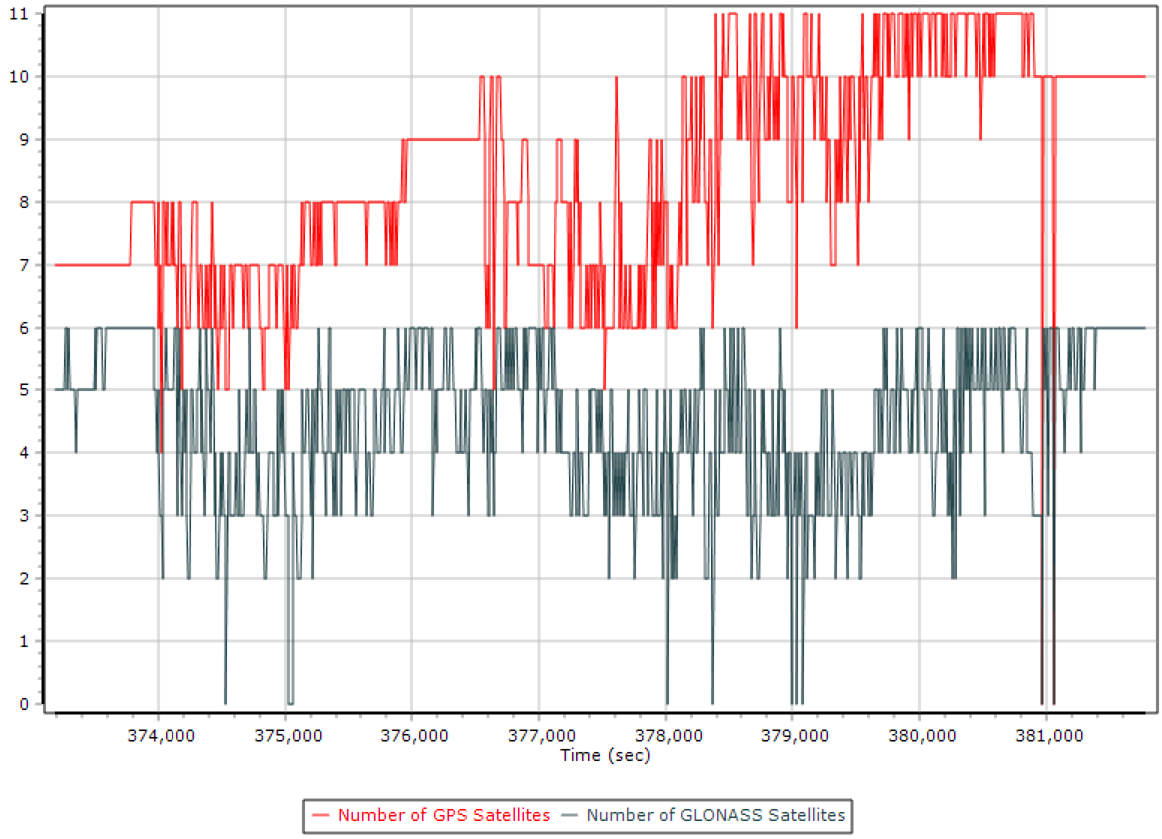


Figure 9: GPS and GLONASS coverage over the time of the survey.

Precise orbit data of the satellites, which help to improve the positioning solution, are usually available a few days after the measurement. The trajectory post-processing started when I.R.I.S 13 returned to Germany. The final trajectory’s absolute position quality is displayed in Figure 10.

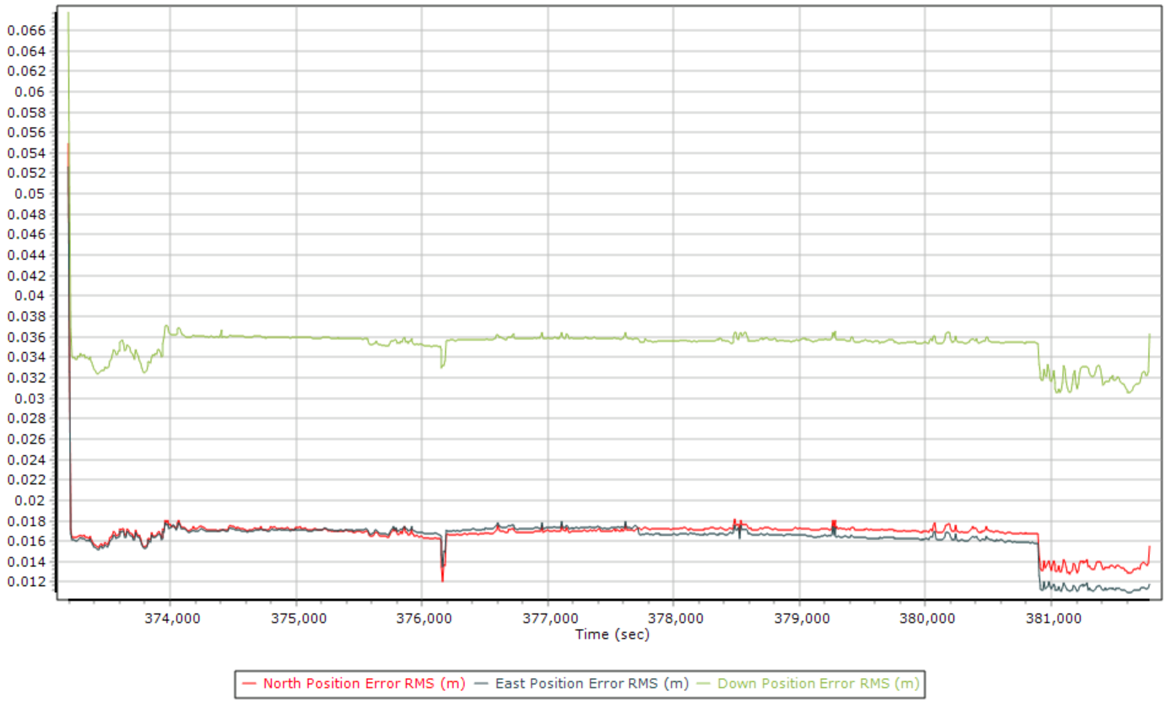


Figure 10: Performance metrics (Root Mean Square Error) of the north, east and down component of the post-processed trajectory.

4.2 Image documentation

For the E8, 3 camera perspectives were taken for each trigger point (every 5m): Frontal view, view to the left and view to the right. Each camera image is located by a precise coordinate. With the help of the image viewers, which make use of camera calibration and vehicle calibration in the background, absolute geo-coordinates can be measured in the photos of the measuring section. In the context of the analysis of the measurement data the image sequences are used for the following purposes:

- to capture surface peculiarities (e.g. material differences)
- to record installations (e.g. bridge transition constructions) which may have an effect on the longitudinal flatness analysis
- Detect large-area, coarse surface damage (e.g. patches, sealed cracks)

The road surface of the approx. 40 km long test section of the E8 is by no means homogeneous, but there are approx. 40 sub-sections which differ in terms of grain size as well as the colour of the material (see Figure 11). The connections between different structural sections are usually not completely flat, but characterized by a surface variation transverse to the direction of travel.

Figure 11: Examples of the different asphalt surface types along the measured track.

In addition to the typing of the surface type, the measurement images can also be used to realize an initial, visual damage detection. Typical surface damages are e.g. cracks or potholes. Figure 12 shows examples of surface damage on the E8. Cracks (transverse cracks) occur most frequently. Potholes are rather rare and then rather small (<20cm diameter). Damaged areas that have already been repaired occur in the form of sealed cracks and very rarely in the form of irregularly contoured, applied patches.

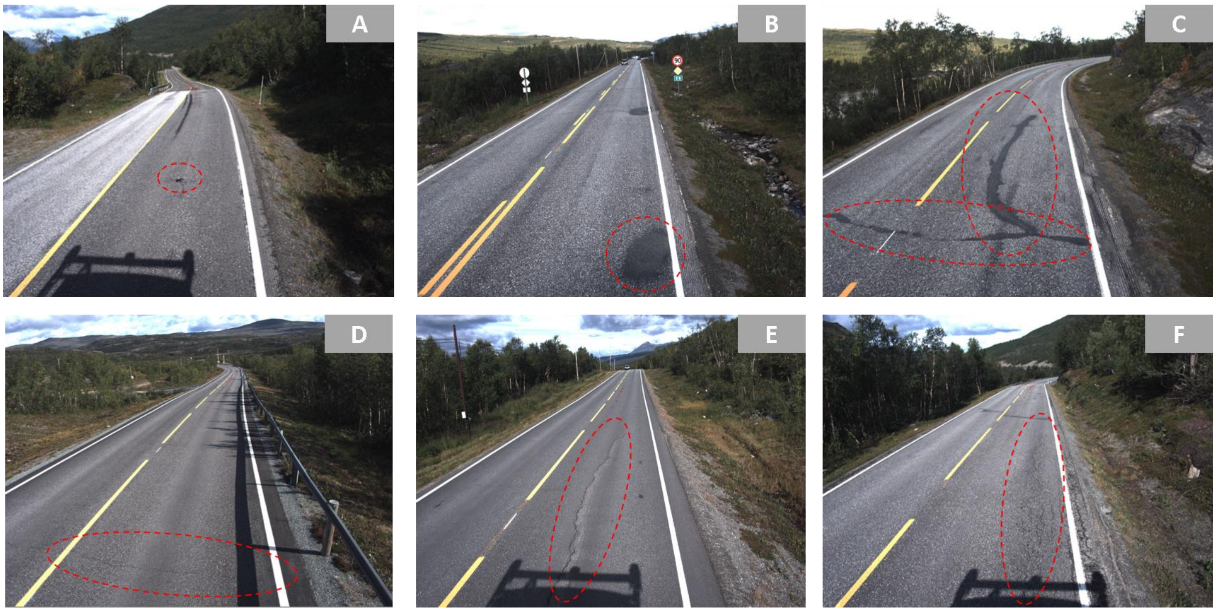


Figure 12: Examples of relevant surface damage. Potholes (A), irregular applied patches (B), sealed cracks (C), transversal cracks (D), longitudinal cracks (E) and alligator cracks (F).

In addition to surface damage, defects on guard rails, condition of markings or other conspicuous features can also be documented and georeferenced using the image sequences. This provides a reliable data basis for modern asset management systems.

Figure 13: Example for a deformed guard rail.

In addition to the applications of the measurement image sequences mentioned above, LEHMANN+PARTNER has implemented automatic object recognition. As a result, each image can be semantically segmented fully automatically. Among others, the following object classes can be detected:

- road surface
- sidewalk / paved surface
- loose ground / gravel / gras
- vegetation / trees
- static objects / poles / guard rails / signs

It should be noted that the implementation is currently still being tested and not yet part of the standard process at LEHMANN+PARTNER. The majority of the data on which the neural network was trained has been collected in urban areas. That`s the reason why the algorithm sometimes has difficulties in separating the asphalted road surface cleanly from the gravel banquet areas.

Figure 14:Automated object detection and classification on image data.

4.3 Extraction of 3D point clouds

Once the trajectory is optimized, 3D point clouds of the LiDAR sensor (PPS+/CPS) can be processed. The standard output format is an ASCII txt file that contains 3D UTM-coordinates X[m], Y[m], Z[m] and the reflexion-intensity value I[12bit] for each measured point. As an optional output we provide the LAZ format.

Figure 15:Perspective view along 3D point clouds from CPS (sparse points) and PPS+ (dense points).

3D point clouds from the PPS + laserscanner are typically used for condition related applications:

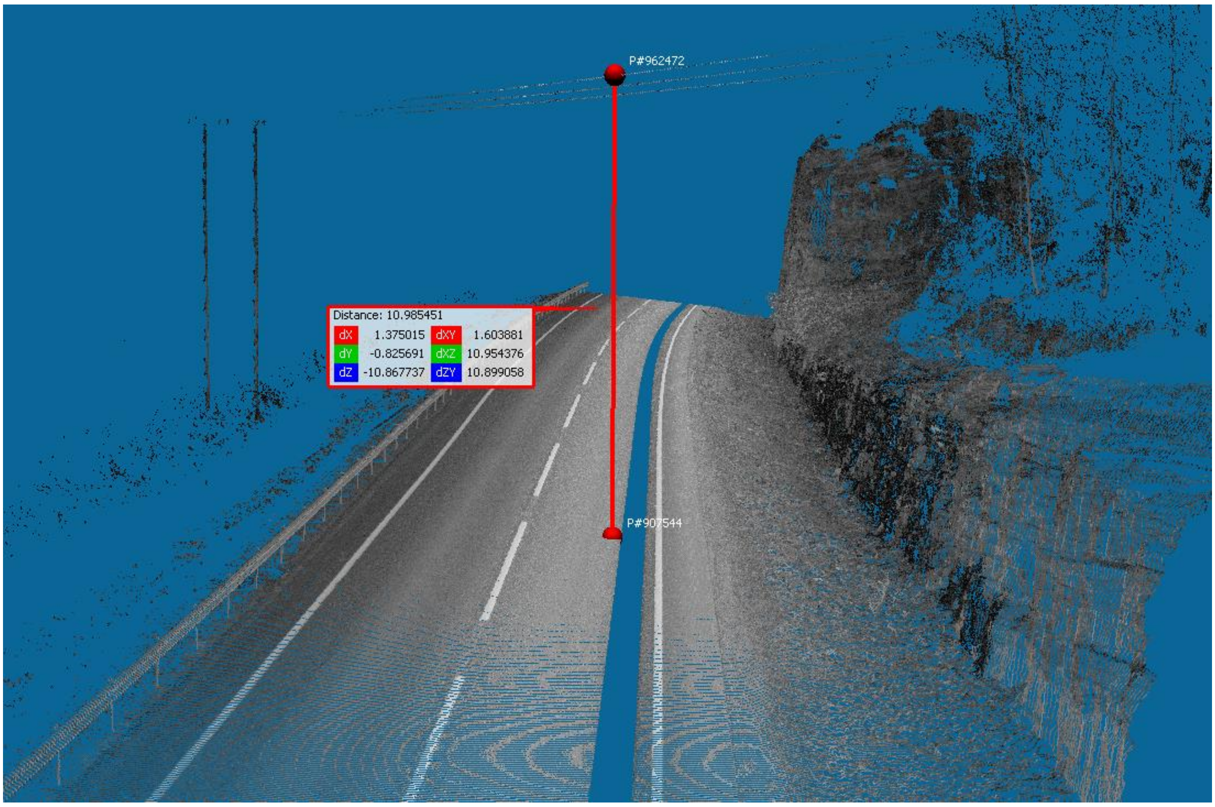
- Evenness evaluation
- Surface damage (> 3mm) evaluation
- Hydrological simulations (e.g. drainage direction)

Figure 16: Possible application for CPS data.

As the CPS is a 350° laserscanner there is a "gap" in its recorded data of 10°. Those 10° are used for an internal control and correction unit. Depending on how the CPS device is mounted on the car, the gap will point towards the ground, the side or the sky. As clearance height determination is a main application for CPS data, the gap is typically located on the ground where it can be "filled" with PPS+ 3D data (see Figure 15).

CPS point clouds are usually utilized when it comes to 3D mapping or measuring applications like:

- 3D position acquisition for specific inventory items (signs, manholes …)
- Clearance height determination under wires or bridges
- Conformity check of planned and actual height of safety barriers
- Generation of maps (roads boundaries, lane markings, inventory, …)



Distance: 10.985451

dX	1.375015	dXY	1.603881
dY	-0.825691	dXZ	10.954376
dZ	-10.867737	dZY	10.899058

Figure 17: Example for 3D distance measuring (e. g. clearance heights under wires) in CPS point clouds.

4.4 2.5D surface models and profile analysis

Based on the raw 3D point clouds of the PPS+ surface models will be computed. There are two types of surface models in the workflow:

- trajectory aligned gridded surface models
- image axis aligned gridded surface models

The first mentioned is a so-called curved regular grid that follows the roads geometry. This high precise surface model allows a quickly access and extract single profiles. The cross sections can then be analysed with regard to rut depth or “fictitious” water depth. With regard to longitudinal evenness indicators the longitudinal profiles can be analysed like Rolling-Straight-Edge, Weighted Longitudinal Profile or International Roughness Index.

In principle, longitudinal and transversal profiles can be extracted and analysed at any position relatively to the recorded lane. The typical resolution of the surface model for this profile analysis is 0.1m by 0.1m (see Figure 18). A resolution down to 0.01m by 0.01m is also possible. According to the German standard by default, longitudinal profiles are only analysed from the right wheel path with a 0.1m sampling interval. In the context of special projects normally three profiles in each wheel path are analysed.

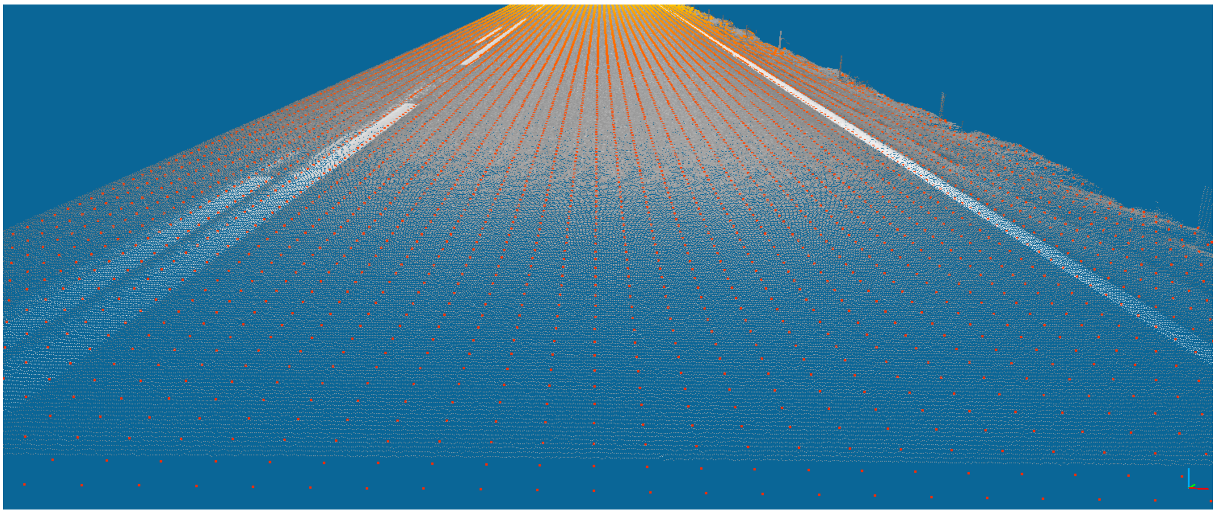


Figure 18: Example of the trajectory aligned surface model (red to yellow) overlaid with the original 3D point cloud (greyscale). At every position of the surface model a longitudinal or transversal profile can be extracted easily.

The second mentioned surface model is a so-called GeoTIFF. This is a common format to work with raster data in GIS environments. It can be interpreted like an aerial photo or a digital elevation model. Typical surface models are:

- absolute / relative elevation models
- shaded relief models
- intensity images

Figure 19: Standard surface models that can be computed from raw 3D point clouds like intensity images, absolute elevation models and shaded relief images in GeoTIFF format (from left to right). Remark: the shaded relief images are massively exaggerated.

Figure 19 shows intensity images apply for delineation of the actual lane. Lane markings can be identified easily because high reflectance of a material results in a bright greyscale vale in the intensity image. Another application is the mapping of surface damages that are characterized by a local radiometric difference like e.g. sealed cracks or patches. In contrast, shaded relief images are best for mapping surface damages that are characterized by local geometric discontinuities like cracks or potholes. Finally, absolute elevation models can be used to directly grab absolute heights of certain points of interest, e.g. the exact height of a man hole cover.

4.5 Evenness indicators

As mentioned, transversal and longitudinal profiles can be extracted from the surface models based on PPS+ data.

4.5.1 Transversal Evenness

As evenness indicators for the transversal profiles we compute rutting parameters like:

- Separate rut depths for ruts in the left or right wheel path (MSPT)
- Separate potential water depths in the left or right wheel path (MSPH)
- Cross slope

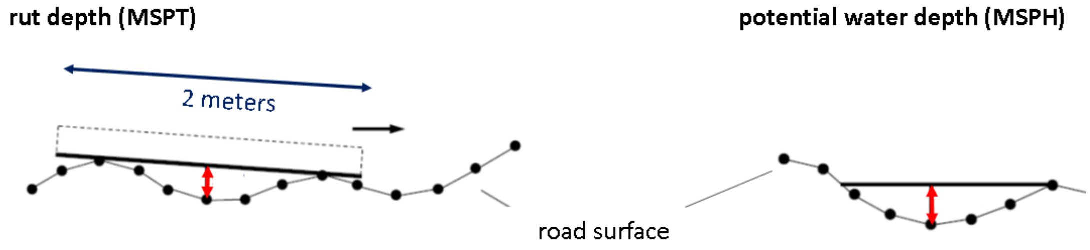


Figure 20: Schematic representation of the rutting indicators MSPT and MSPH (see: FGSV 2018).

The single transversal profiles are averaged over 1m and then the rutting parameters are computed. For this, the straight edge model is used (see Headley & Meyers 1991, Bennett 2002). The virtual reference bar has a length of 2m. The lane profile is not considered as a whole, but rather as a separated into left and right lane part. Starting from a starting point, a connecting line is drawn to each point that has a maximum distance of 2 m from the starting point. From all intermediate points the distance to the straight line is calculated and the maximum value is stored. Then the start and end points move on and the procedure is repeated. Finally, the largest of all temporarily stored maximum depth values is determined and defined as the maximum rut depth (see Figure 21).
The potential water depth indicator describes the height of the water level standing in the rut under the assumption that water is constantly falling on the single profile.

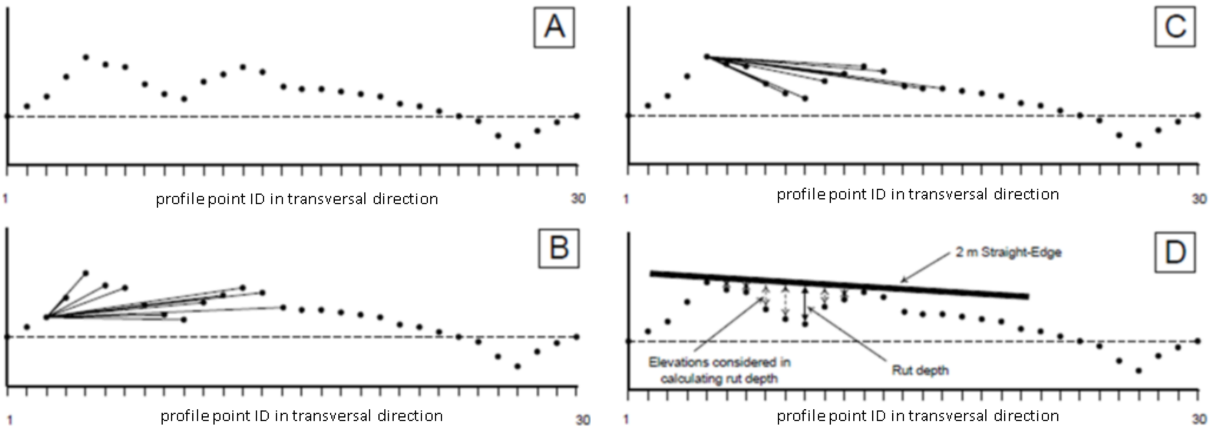


Figure 21: rut depth calculation using a virtual 2m straight edge (see: Bennet 2002)

Figure 22 shows the extraction of a single transversal profile (based on the trajectory-aligned surface model) as an overlay over a shaded relief image that qualifies the spatial expression of the rutting.

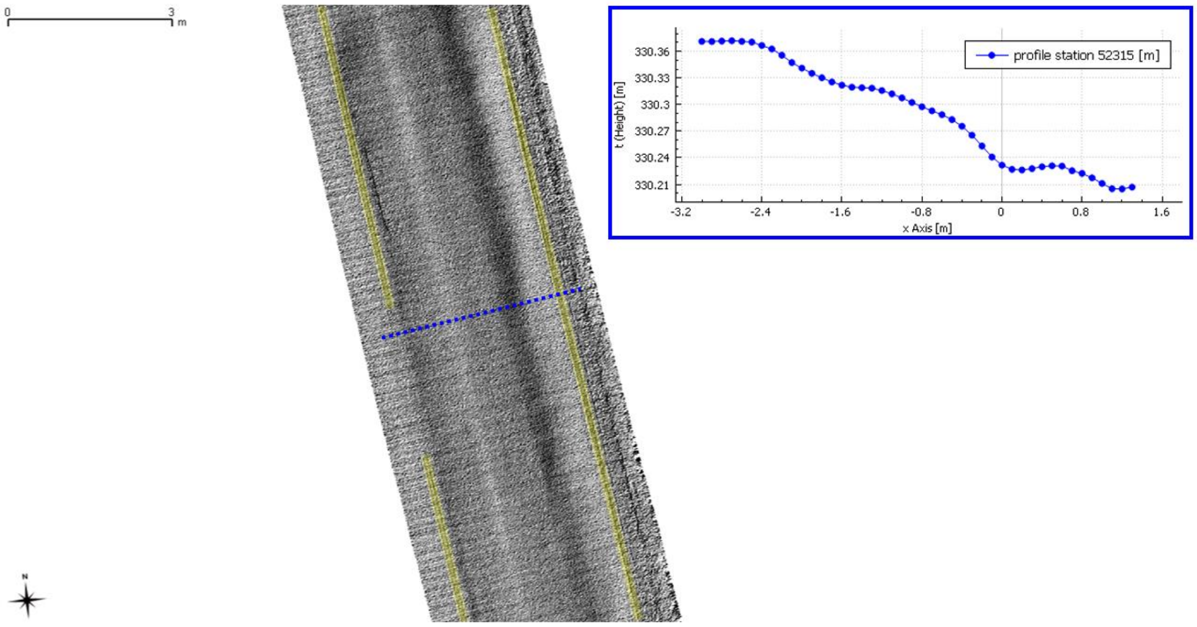


Figure 22: Example for severe rutting near Helligskogen. The shaded relief visualization of the surface model indicates the rutting in both wheel paths. The lane markings are highlighted in yellow. The transversal profile analysis shows that the rutting in the right wheel path is more severe than in the left wheel path.

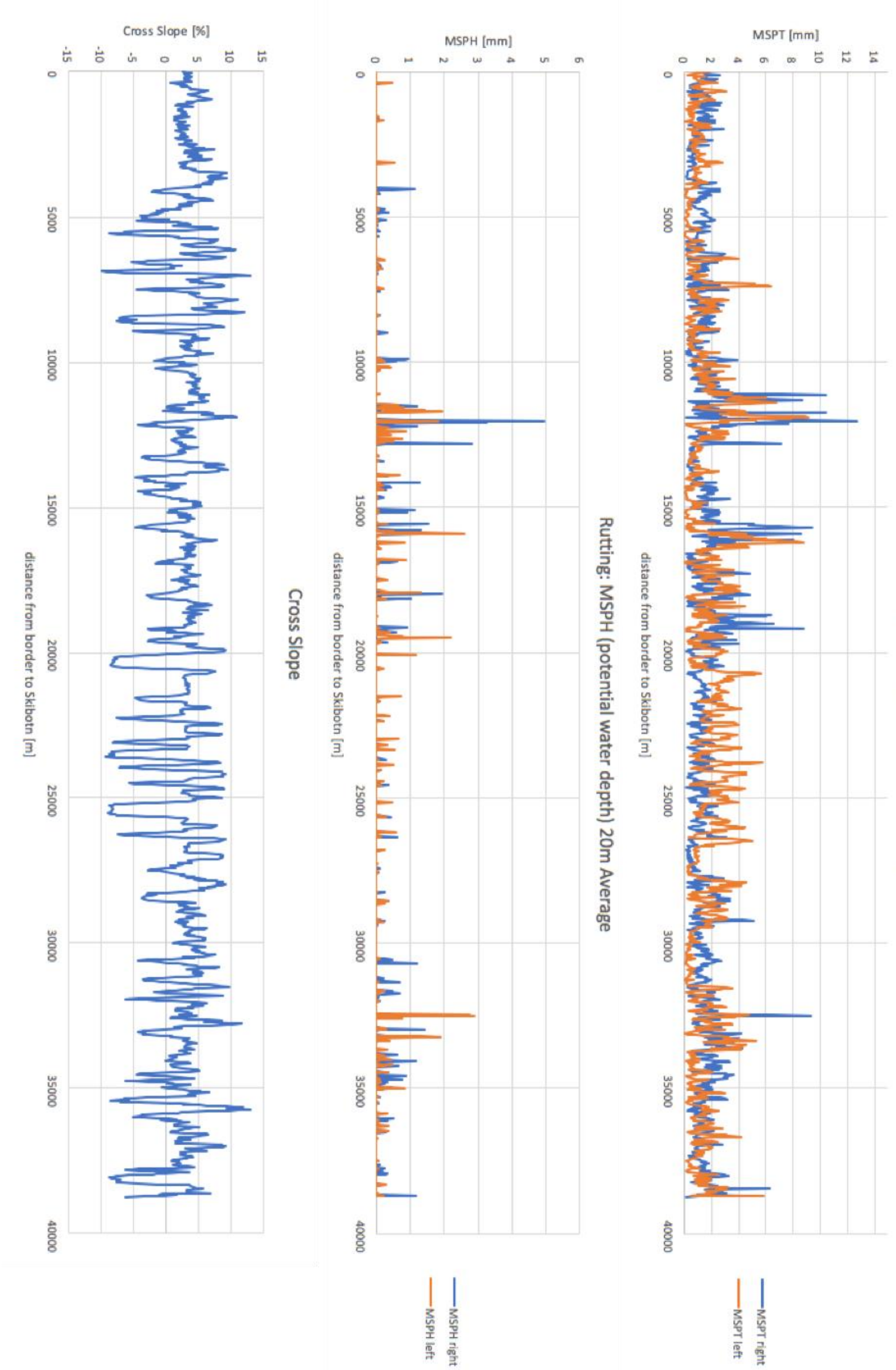


Figure 23: Rutting analysis based on the transversal evenness indicators rut depth, potential water depth and cross slope. All values in the plots are averages over 20 m distance.

In Germany (see FGSV 2018), the threshold for a good highway or country road surface is up to 10 mm (on urban roads: 20mm) for MSPT and 4 mm (in urban roads: 8mm) for MSPH. For the German standard, the rutting values are averaged over 1 m whereas the plots in Figure 23 show values that are averaged over 20 m. The cross slope values are positive for gradients to the right and negative for gradients to the left (in driving direction). The cross slope values are averaged over 20 m too.

As shown in Figure 23 rutting is an issue for bad condition from kilometre 12 to 13. In most cases the rutting in the right wheel path is more severe than in the left one. In interaction with the cross slope, the values of the potential water depth draw a comparable picture.

4.5.2 Longitudinal Evenness

As indicators for longitudinal evenness the international roughness index (IRI) and the planograph simulation (PGR) was computed. The IRI is a standardized roughness measurement and defines a characteristic of the longitudinal profile. IRI values allow conclusions to be drawn about the ride quality experiences by backseat passengers because they are highly correlated to vertical passenger acceleration. A mathematical model is used to calculate the total vertical movement by one wheel of a vehicle as it travels over the pavement. The IRI is based on the average rectified slope. This is a filtered ratio of a standard vehicle's accumulated suspension motion (e.g. meters) divided by the distance travelled (e.g. kilometres). For more details please refer to Figure 24 and Nikolaides (2014 pp. 752-754). The IRI algorithm is implemented according to DIN EN 13036-5.

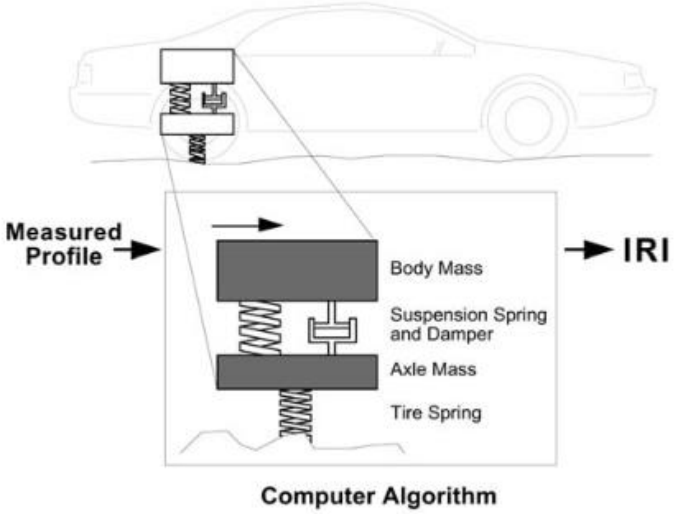


Figure 24: Schematic representation of IRI as a quarter-car simulation of road roughness (see: ACPA 2002)

The PGR is a common indicator for longitudinal evenness in the German standard evaluation process. The core of this indicator is to quantify the maximum deviation under a 4m long, static bar that is moved over a virtual longitudinal profile. This indicator is very comprehensive and comparable to evaluations using conventional equipment, where a tiny wheel in the middle of a 4-meter-long rolling traverse construction moves up and down as the morphology of the underlying road surface changes. The implementation of the planograph simulation is easy as well: for a given 4-m segment of the longitudinal profile a straight edge is fitted onto the highest profile points. Then the distances are computed (point to line) and the maximum distance is stored. Then the virtual bar is shifted forward along the profile and the procedure is repeated.

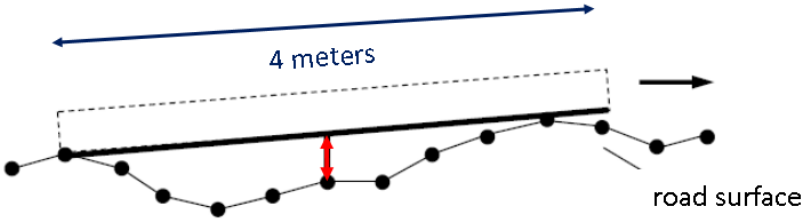


Figure 25: Schematic representation of the longitudinal evenness indicator PGR that quantifies the maximum deviation under a 4m bar (see: FGSV 2018).

The PGR-Max threshold for a road surface with good condition is 4mm. According to FHWA (2016), typical acceptable IRI values range from 0.810 to 1.030 m/km for new asphalt highway pavements.

The interpretation of the IRI signal leads to the conclusion, that there are at least 4 segments of (more or less) homogeneous IRI plateaus: from kilometre 0 to 11, then on a slightly higher level from kilometre 11 to 20, then significantly low IRI level from 20 to 28 and then from kilometre 28 to the end of the track almost on the same level like the second IRI plateau. The peaks typically correspond to singular events like bridge construction joints or the transitions of two surface types like mentioned in chapter 4.2. The PGR signal supports the IRI values, although it should be noted that the PGR has only limited significance, as wavelengths over 4 metres are not taken into account.

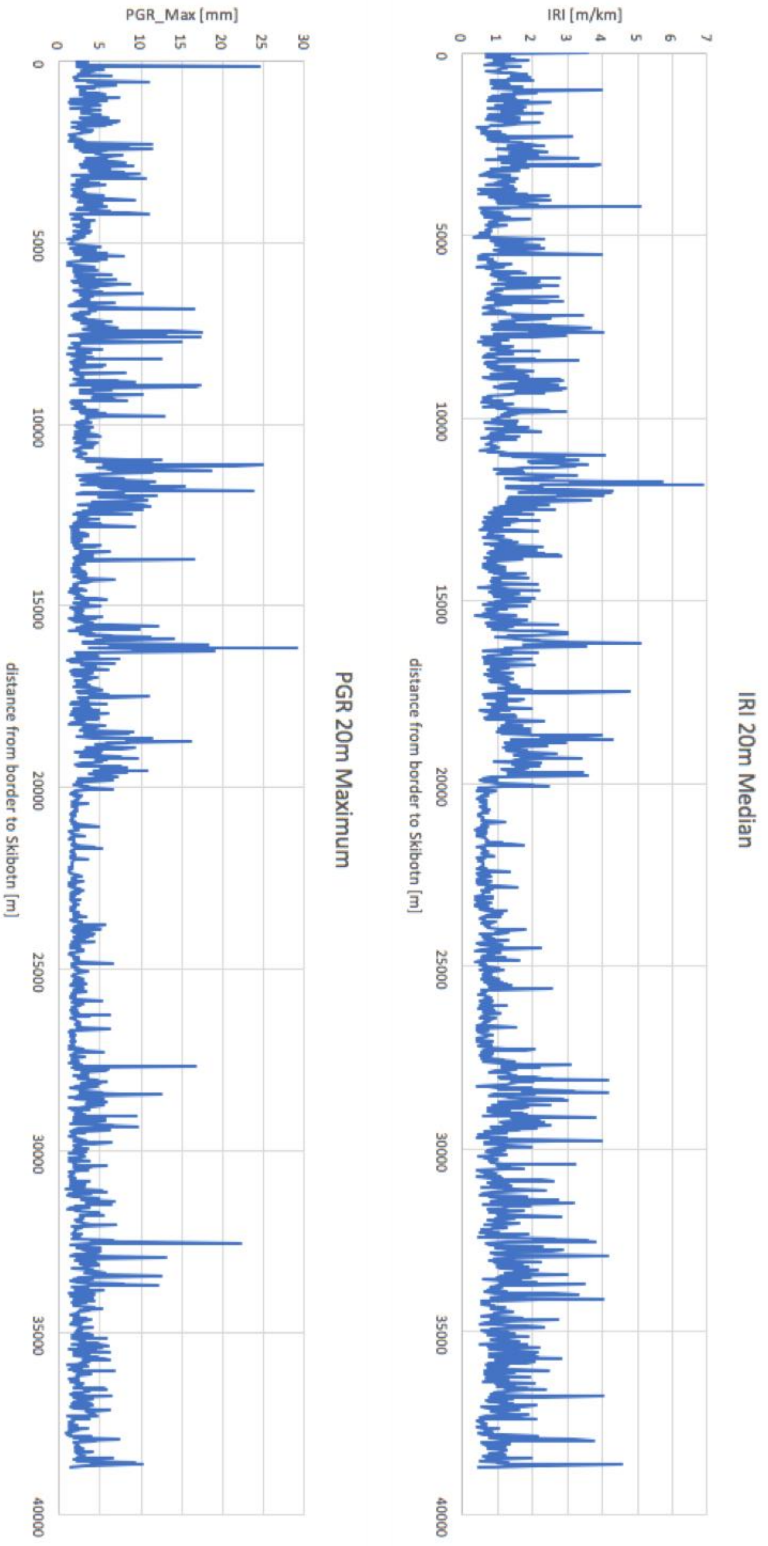


Figure 26: Longitudinal evenness indicators IRI and PGR.

4.6 Surface images and surface condition evaluation

The 2D unit of the PPS+ records surface images with a spatial resolution up to 1.2mm. Based on this data, surface defects (cracks, potholes, patches, …) and surface features (lane markings, manholes, …) can be analysed precisely.

LEHMANN+PARTNER provides a surface condition evaluation with regard to the German technical requirements (see FGSV 2018). The principle is visualised in Figure 27. Although the sensors would allow a much finer damage analysis (object sharp), in this report the procedure is used which is prescribed by the German regulations for motorways and highways. If network-wide acquisition and evaluation is the goal for strategic and operational maintenance management, then the generalization approaches of the German standard offer a valid basis for this.

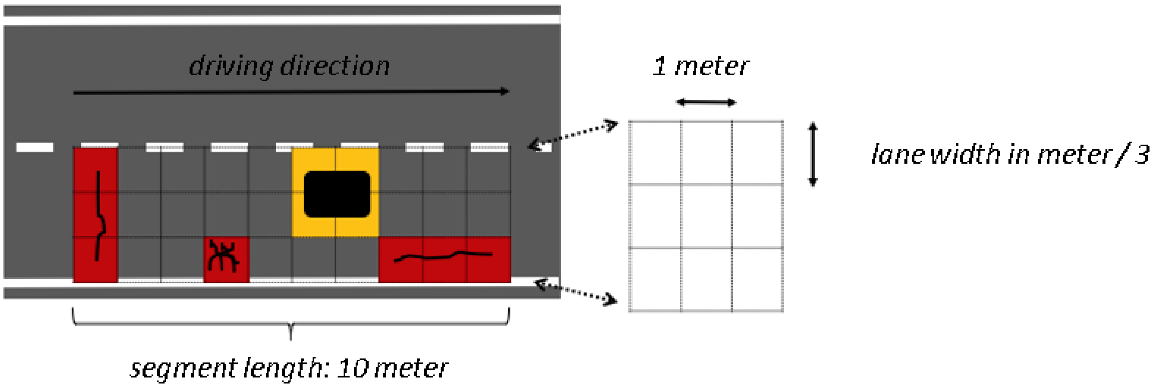


Figure 27: Principle of the condition evaluation according to German standard (see FGSV 2018). In this example the 10-meter-long segment would have the indicators 23% cracks and 13% patches.

The core of the analysis scheme that can be seen in Figure 28 is that a grid of approx. 1*1m cells is applied to a lane segment. Each segment is exactly 10 meters long and it is represented by one single surface image. If a surface damage falls into a cell of the analysis grid then all the cells that are affected by this damage are activated. For roads constructed using asphalt, the German regulations have 6 types of distress:

- cracks
- potholes
- patches (inlaid vs. applied patches)
- open construction seams
- bleeding

For the analysis in this report, there are some modifications to the standard procedure of analysis:

- Normally, all possible types of cracks (open, sealed, net cracks, single cracks) are subsumed under the class "crack". To represent the characteristics of E8 better, we decided to distinguish between open and sealed cracks.
- Open construction seams are treated as open cracks.
- Carving or grinding marks (e.g. from winter service) are excluded from the analysis.
- Bleeding is a very difficult damage type especially when the surface is not recorded under completely dry conditions. We discarded bleeding from the analysis.

Based on the analysis grid, an indicator is calculated for each damage class, which makes it possible to assess the evaluation section in the context of a network-wide perspective. This indicator describes the proportion of the damage affected lane area. Finally, each individual damage class has its own indicator.

For the analysis in this report, there is a minor modification to the standard indicators:

- Normally, if a pothole is present in one grid cell of a segment, the whole segment is activated. To keep the damage analysis uniform, we applied the same procedure to potholes as for all other classes: only grid cells that directly intersect with a pothole are activated.

The primary data source for condition evaluation is the surface image produced by the 2D unit of PPS +. According to the German Standards they have a length of 10 m and a width approx. 4.6 m. As a secondary data source, the frontal camera image is used to verify decisions that may need some more context information. This can be seen in Figure 28.

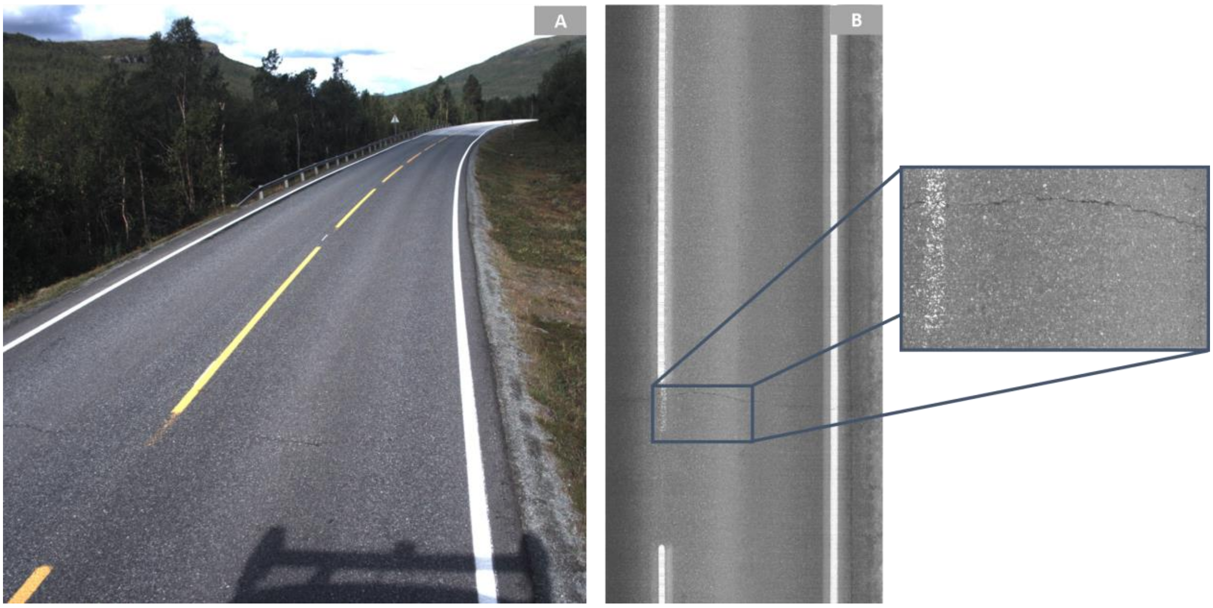


Figure 28: Example for the surface damage analysis based on surface images. A shows the frontal camera image. B shows the surface image captured by PPS+. At the right there is a close-up of the transversal crack.

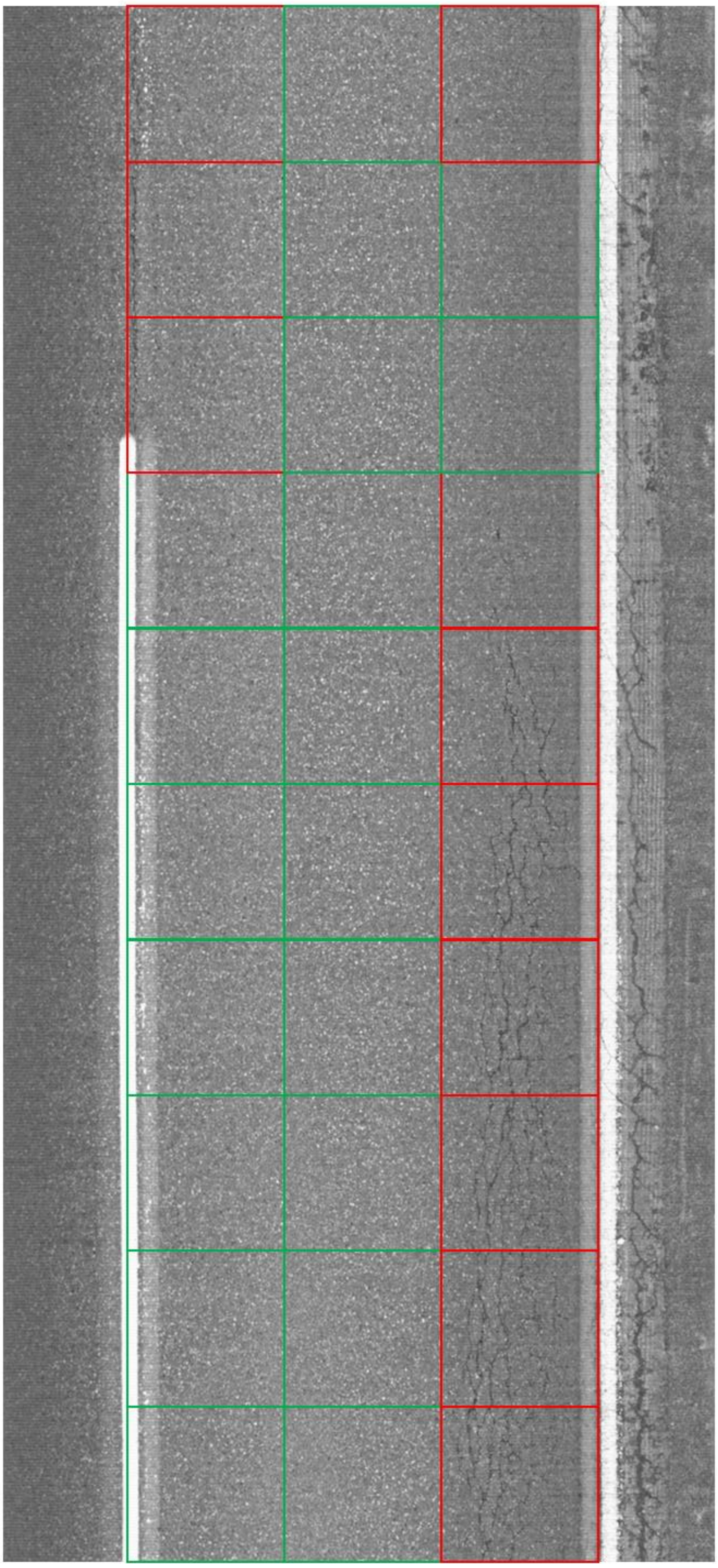


Figure 29: This surface image example is located almost in the middle of the E8 nearby the bridge over the Rovvejohka river (driving direction: to Skibotn). The surface condition indicator for crack here is 36% because 11 of 30 grid cells are occupied with cracks.

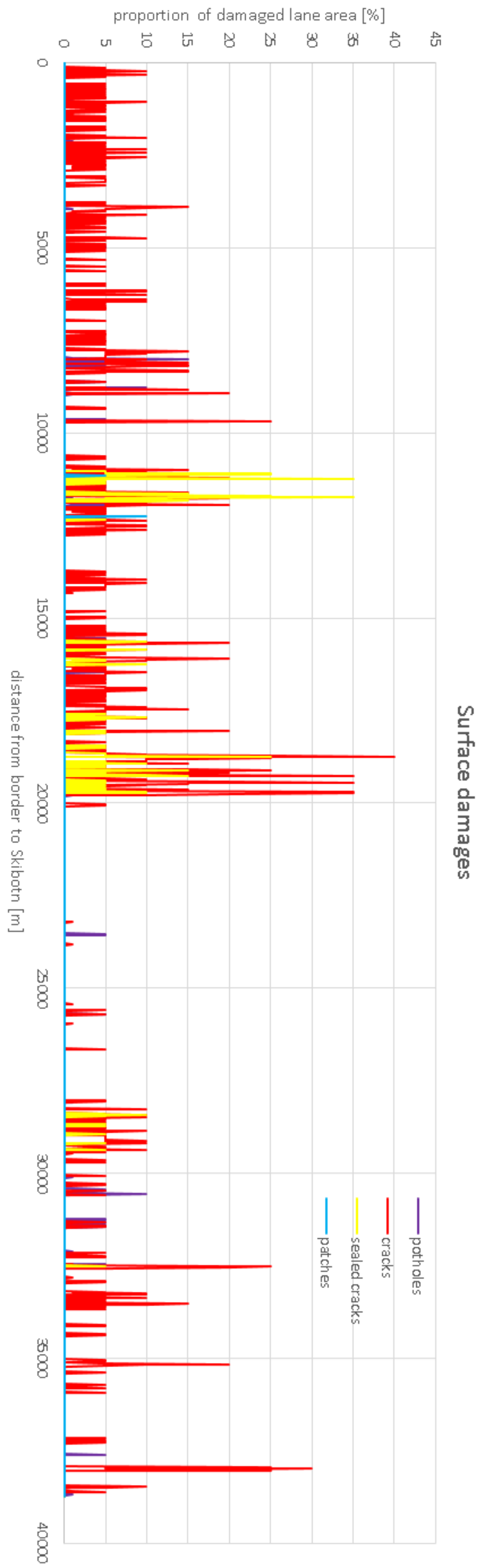


Figure 30: Overview over the surface damage occurrence, damage types and the proportion of damaged lane area.

Figure 29 shows a PPS + surface image and the corresponding analysis damage grid. It also shows that damages outside the lane boundaries are not evaluated. At the end, all indicators were calculated in relation to an evaluation length of 20 metres in order to obtain evaluation segments that match those of the evenness analysis.

The most common damage type is cracking. Around kilometre 12, 16, 19 and 29 there are areas that have been maintained in the past and cracks have been sealed. Very often those sealed cracks are at least partly open cracks. Potholes are very seldom and if they occur, they are of relatively small size. As can be seen in Figure 30, the surface condition reflects the results of the evenness evaluation: the best condition can be found between kilometre 20 and 28.

4.7 *Corridor analysis example: clearance heights*

Based on the 3D point clouds of the CPS laserscanner clearance height can be computed. This type of information is, for example, important for the route guidance of heavy goods transports. Relevant objects to be measured are for example:

- wires / power cables
- tunnels
- overpasses
- sign over the road

As there are no overpasses or tunnels along the E8, the analysis in this report is limited to cases where power cables were routed over the road or other constructions occurred (see Figure 31 and Figure 32). The overall minimum clearance height found was 5.25 m (power cable).

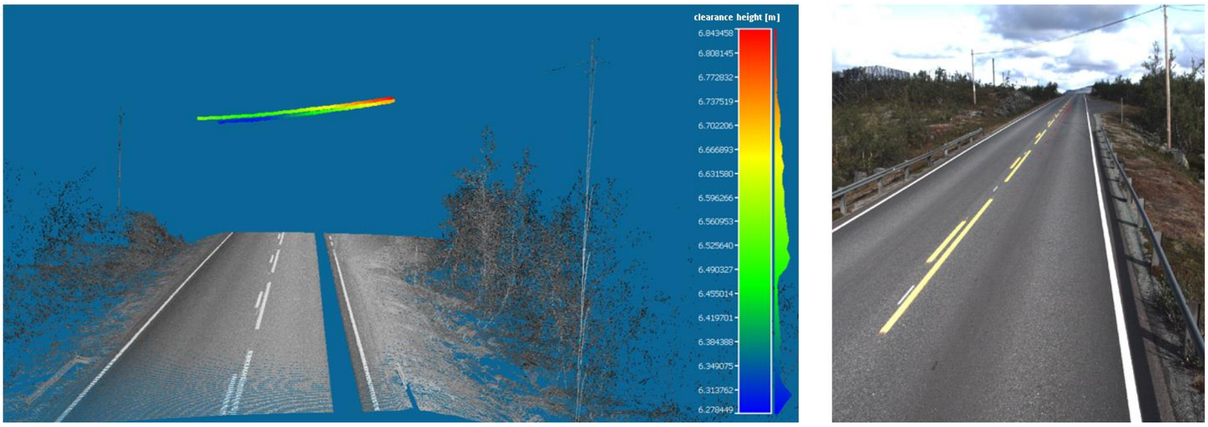


Figure 31: Example evaluation of power cable clearance heights. In this case the lowest clearance height is 6.27 m (blue points).

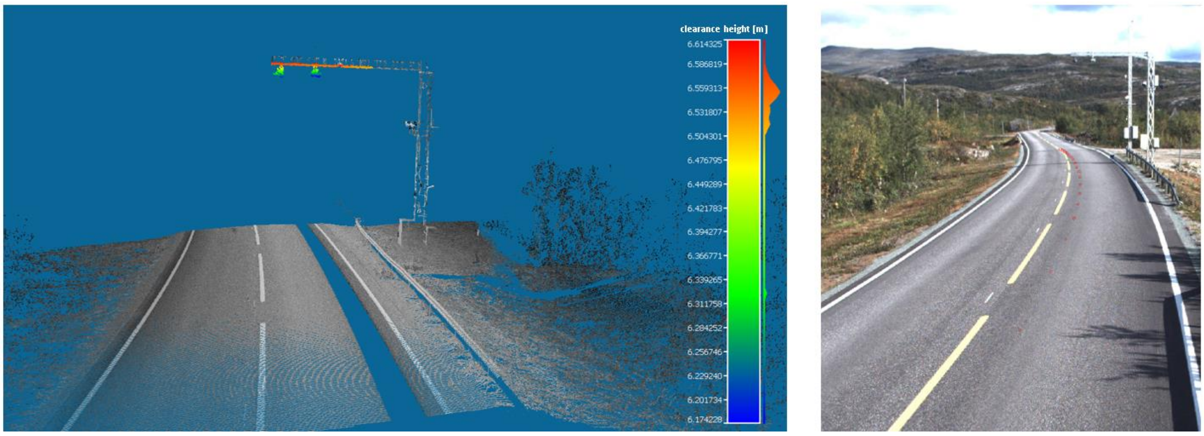


Figure 32: Example of a toll station over the right lane. In this case the lowest clearance height is 6.17 m (blue points).

5 Conclusion

This report demonstrated the data acquisition and analysis with the hardware, software and workflows provided by LEHMANN+PARTNER.

A detailed analysis will be presented as:

- Excel file for each measurement direction containing all evaluated evenness and surface condition metrics
- Shapefiles for each measurement direction containing all evaluated evenness and surface condition metrics
- Shapefile with the minimum clearance heights

The processed data products will be delivered on a hard drive:

- 3D point clouds (PPS +)
- 3D point clouds (CPS)
- Surface images (PPS +)
- Surface models (PPS + and CPS)
- Camera images (3 perspectives)

A schedule for the final data delivery and the details on how to present the data (desktop-based vs. web-based) will be discussed with the customer.

6 References

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DIN EN 13036-5: Oberflächeneigenschaften von Straßen und Flugplätzen - Prüfverfahren – Teil 5: Bestimmung der Längsunebenheitindizes; Deutsche und Englische Fassung prEN 13036-5:2017

FGSV (2018). Zusätzliche Technische Vertragsbedingungen und Richtlinien zur Zustandserfassung und -bewertung von Straßen ZTV ZEB- StB, Köln: FGSV-Verlag.

FHWA (2016): Measuring and specifying pavement smoothness. https://www.fhwa.dot.gov/pavement/pubs/hif16032.pdf

Hadley, W. O. & M. G. Myers, (1991): Rut Depth Estimates Developed from Cross Profile Data. Texas Research and Development Foundation. Austin: s.n., 1991. SHRP Long Term Pavement Perfomance Program Technical memo AU-179.

Nikolaides, A. (2014): Highway Engineering: Pavements, Materials and Control of Quality.

CRC Press.

Attachment 4

TERRATEC

Leveranserapport E8 Borealis

1 Innholdsfortegnelse

1. Generelt

1.1 Oppdragsgiver

Statens Vegvesen
Region Nord
Postboks 1403
8002 Bodø
Kontaktperson: Per Otto Aursand

Prosjektnavn: E8 Borealis

1.2 Oppdragstaker

Terratec AS
Vækerøveien 3
0281 Oslo
Prosjektleder: Tobias Jokisch

Terratec sitt oppdragsnummer: 50521 / 11172

1.3 Oppdragsinfo

Statens vegvesen har definert strekningen på E8 mellom Skibotn og den finske grensen som en teststrekning for ITS systemer, og traseen har fått navnet E8 Borealis. Langs denne strekningen er det også ønskelig å samle inn data fra ulike avanserte måleinstrumenter med laser og georadar som tilbys av markedet.

Terratec opererer to laserskanningssystemer. Et system fra Optech Lynx-system med 360-graders kamera samt et ViaPPS-system fra den norske leverandøren ViaTech. Optech Lynx er optimalisert for kartlegging av sideterreng og objekter langs veibane, mens ViaPPS er utviklet spesielt med tanke på kartlegging av spor og jevnhet.

I oppdrag med hensikt å registrere spor og jevnhet vil Terratec normalt benytte ViaPPS-systemet der både målepresisjon er optimalisert for denne typen analyse og rapportering tilpasset leveranser til SVV sine systemer. Ettersom Statens vegvesen selv stiller med ViaPPS i testprosjektet er det ønskelig fra Statens vegvesen at Terratec viser hvilke andre muligheter og bruksområder som finnes med utstyr og programvare på markedet.

Georadarsystemet som benyttes av Terratec er norskprodusert stegfrekvens georadar fra 3D-Radar.

Denne rapporten omhandler arbeidet som er utført og de produktene som er levert fra laserskanning og georadarundersøkelsen.

1.4 Koordinatsystem

Dataleveransen er foretatt i følgende koordinatsystemer:

Euref 89 UTM 33, høyder i NN1954

1.5 Nøyaktighet

Den absolutte nøyaktigheten av dataene er avhengig av GNSS-forhold under datainnsamlingen. Det er ikke utført målinger av kontroll- eller justeringspunkter for å forbedre posisjonsnøyaktighet.

1.6 Levering av digitale data

Data er levert på Terratecs FTP-server

1.7 Oppbevaringssted for benyttet materiell

All rådata er lagret hos Terratec AS og oppbevares i 5 år etter leveranse.

1.8 Kvalitetssikring

Kvalitetssikringstiltak er utført etter Terratec AS sitt kvalitetstyringingssystem.

1.9 Rapporter

Rapporter tilhørende prosjektet leveres digitalt, kopi lagres hos Terratec AS sammen med rådata.

2 Datainnsamling

Det er gjennomført laserskanning fra bil – mobile laser scanning (MLS).
Georadarinnsamling (GPR) ble gjennomført samtidig.
I de kommende avsnittene er utført datafangst og bearbeiding av data beskrevet.

Laserskanning fra bil ble utført for å etablere en heldekkende og nøyaktig punktsky for veianalyse. Georadarinnsamling skulle avdekke veioppbygningen altså lagtykkelse av veidekke og veifundament samt dybde til fastfjell der synlig. Begge kjørefelt ble scannet.

2.1 Personell

Terratec har benyttet følgende personell til datainnsamling:

Ole Jørgen Halle	Operatør
Tobias Jokisch	Geofysiker

2.2 Sensorsystem MLS

Laserskanningen ble utført ved bruk av Optech Lynx SG1 Mobile Mapper. Dette laserskanningssystemet består av to skråstilte 600 kHz pulsskannere, fire integrerte kameraer på taket, et 360-graders Ladybug kamera, posisjoneringssystem med IMU/GNSS-sensorer samt DMI på bilhjulet. Systemet er montert på en Toyota Landcruiser (se figur 2).

Se tabell under med spesifikasjoner.

Element	Ytelse
Maksimalt antall målepunkter per sekund	1 200 000
Returpulser	Opptil 4 (1,2,3 og siste)
Rotasjonsfrekvens per lasersensor	250 Hz
Skannevinkel (Field of View)	2 stk x 360 °
Rekkevidde avstandsmåler	250m ved 10% refleksjon
Presisjon avstandsmåler	± 0.5 cm (1 sigma)
GNSS / IMU	Applanix POS/LV 610
Optech kamera, pekende bakover og til siden	4 stk x 5 Megapixel
SONY 4K FDR-X1000V videokamera	Full HD
Point Grey Ladybug 360°-kamera	6 stk x 5 Megapixel

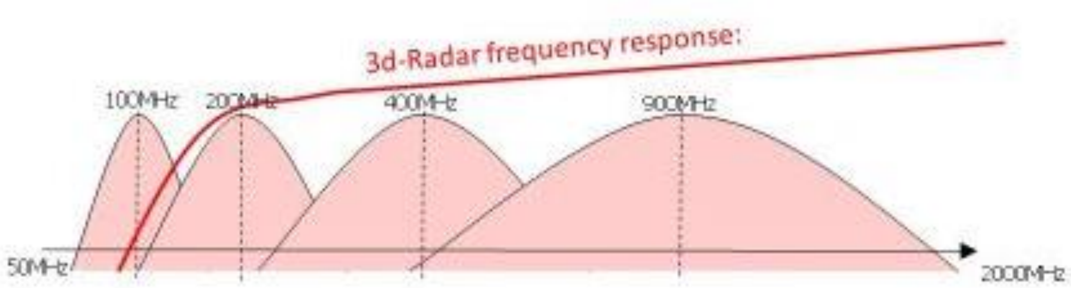
2.3 Datainnsamling Georadar

Georadar eller ground-penetrating radar (GPR) er en elektromagnetisk geofysisk metode som gjør det mulig å undersøke undergrunnen på en ikke-destruktiv måte. Elektromagnetiske bølger sendes ned i bakken og de elektromagnetiske bølgene som reflekterer der det er en forandring i de elektriske egenskapene mellom to lag blir så mottatt. Georadar kan brukes til ikke destruktiv undergrunnskartlegging av infrastruktur eller grunne geologiske strukturer. For infrastrukturundersøkelser kan georadar brukes til å identifisere, måle og kartlegge undergrunnsfunksjoner som asfalttykkelse, posisjoner av armering, posisjon av rør etc. i undergrunnen under en vei eller bro.

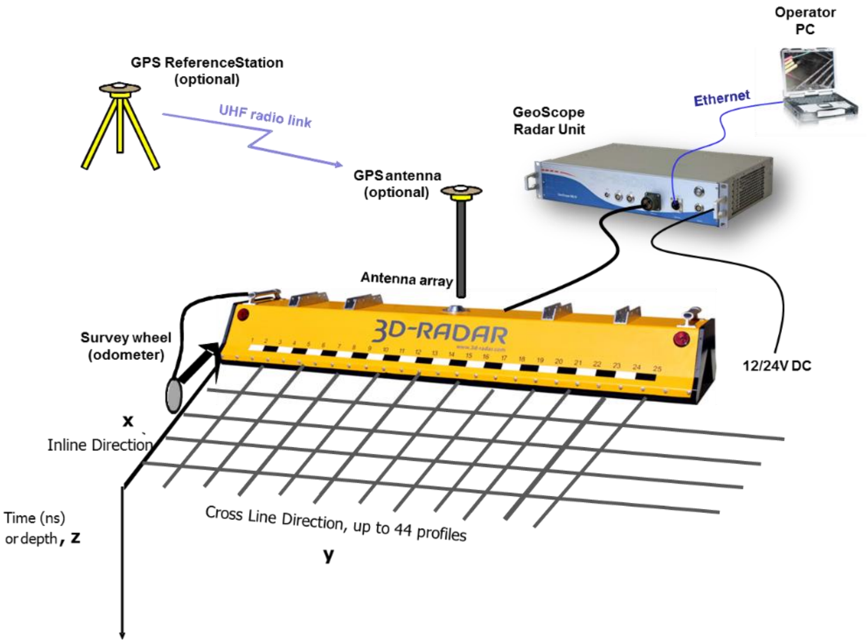
2.3.1 200-3000MHz antenne

Dataen ble samlet inn ved hjelp av en luftkoblet 3Dradar antenne som er basert på steg-frekvens prinsippet. Istedenfor en puls med fast senterfrekvens sendes det ut en serie av sinus-bølger med faste, økende frekvenser. Frekvensbåndet er dermed mye bredere og signalet skarpere, noe som øker oppløsningen (se Figur 1). Samtidig består 3Dradar'en av flere sender-mottaker som til sammen gir opptil 25 profiler samtidig i en avstand av 7,5cm (se skjematisk oppsett i Figur 2). Figur 3 viser et bilde av oppsettet som ble brukt under innsamlingen.
For å kunne holde en høy hastighet ble antall kanaler redusert til 13, se tabell på neste side med spesifikasjoner.

Element	Ytelse
Frekvensbånd	200-3000MHz
Time window	50ns
Dwell time	1 mikros
Inline sampling (langs kjøreretning)	8cm
Xline sampling (på tvers av kjøreretning)	7,5-22,5cm
GNSS / IMU	Applanix POS/LV 610



Figur 1: Frekvensspektrum 3Dradar



Figur 2: Skjematisk oppsett av Geoscope GPR og 3Dradar antenne


Figur 3: Oppsett brukt under innsamlingen

2.4 Gjennomføring

Datainnsamlingen ble gjennomført 20.8.2019 (GPR) og 21.08.2019 (MLS).

For vegene ble det samlet inn data i begge kjørefelt. Kjørehastigheten var 70-80 km/t (50km/t for GPR innsamlingen). Opptak av Ladybug-bilder ble gjort med frekvens 1 bilde per sekund. Samtidig med laserskanningen er det også foretatt opptak av video.

2.5 Vanskeligheter

GPR innsamlingen foregikk uten problemer.
Før og delvis under innsamling av MLS data var det lett regn. Våt bakke vil ha gjort punktsky noe mer støyete enn normalt, samt intensitetsverdier generelt mørkere. Dette vil påvirke analysearbeid med tversgående ujevnheter minimalt, men det kan gjøre det vanskeligere å detektere små endringer i punktsky, som sprekker.
Nordgående kjøring hadde tørrest veioverflate og ble brukt til videre veianalyse.

3 Prosessering laserskanning

3.1 Personell

Følgende personell har vært ansvarlig for prosesseringsarbeid:

Jakub Sroka	Kvalitetssikring og kontroll
Morten Rudi	Prosesseringsansvarlig MLS

3.2 Programvare

Følgende programmer har vært brukt til behandling av data i prosjektet:

Programvare	Versjon	Anvendelse
TerraPos	2.4.90	Navigasjonsprosessering
Optech LMS	4.3.0	Ekstrahering av punktsky og bilder
TerraScan	019.006	Behandling av punktsky
TerraMatch	019.002	Matching av MLS-punktsky
TerraPhoto	019.003	RGB-fargelegging
TerraModeler	019.002	Generering av TIN-modell
TopoDOT	11.5.0.5	Vektorisering av objekter

3.3 Preprosessering av punktsky

3.3.1 Navigasjonsløsning

For å georeferere punktskyen ble det benyttet data fra systemets navigasjonssensorer, samt GNSS data fra referansestasjoner (ETPOS-tjenesten fra kartverket).

De anvendte referansestasjoner i det aktuelle oppdraget er BALC, OLDC, OVEC, og SKIB.

Navigasjonsløsning ble beregnet i den Terratec-utviklede programvaren TerraPos. Ved å integrere data fra de ulike navigasjonssensorene, samt referansestasjoner, fremskaffes en best mulig kontinuerlig bevegelig posisjon og orientering for sensorene.

Videre ble punktskyene ekstrahert i aktuelt koordinatsystem ved programvare tilknyttet lasersensoren, Optech LMS.

3.3.2 Matching av MLS-punktsky

Matching av punktskyen gjøres for å øke nøyaktigheten på georefereringen og for å få en mer homogen punktsky. Korreksjonen beregnes som en funksjon av tid i programvaren TerraMatch. Denne korreksjonen kan beregnes for både XY og Z.

Med utgangspunkt i prosjektets nøyaktighetskrav og analyse av inndata ble det bestemt å kun matche de to kjøringene mot hverandre i Z. En manuell kontroll viser at kjøringene stemte innen 0-4 cm i analyseområdet.

3.4 Klassifisering av laserdata

Det har blitt foretatt en helautomatisk klassifisering av punktskyen med påfølgende manuell kontroll. Hver kjøring er bakkeklassifisert separat for at analyse ikke skal påvirkes negativt av at data ikke er matchet i XY. Bakkeklassifisering var en hard surface-klassifisering med fokus på veioverflate og er ikke kvalitetskontrollert utover veioverflate i analyseområdet.

Det er foretatt en klassifisering av punktskyene i følgende klasser:
00 Uklassifisert – uklassifiserte punkter innen 5 cm av bakke
01 Uklassifisert – uklassifiserte punkter ellers
02 Bakke – bakkeklassifiserte punkter til bruk i analyse

3.5 RGB-fargelegging av punktsky

Bildene tatt med Ladybug 360°-kameraet er brukt til å fargelegge punktskyen med RGB-farger. Kameraet er kalibrert mot punktskyen for å få en best mulig geometrisk nøyaktighet av fargene, dvs. at de samme objektene i bildene og i punktskyen overlapper i størst mulig grad. Kalibrering og fargelegging ble gjort i TerraScan og TerraPhoto.

Den geometriske nøyaktigheten til RGB-fargelegging er avhengig av kamerakalibrering, forholdet mellom pikselstørrelse og punktstørrelse, plattformens endring i posisjon mellom laserskanning og bildetaking av ett objekt, samt flere andre faktorer. Det gjør at den ikke er lik overalt. Punktsky vist i RGB-farger bør kun brukes som støtte i vektorisering og til visualisering. Det er intensiteten til punktene som gir det mest korrekte bildet av geometrien.

4 Veianalyse

Veianalyse ble gjort i programvaren TopoDOT. TopoDOT er i integrert i Bentley MicroStation og er programvare designet for hel-, og delautomatisk analyse og kartlegging av punktsky, spesielt av jernbane og vei.

All veianalyse ble utført på nordgående kjøring ettersom den hadde tørrest veidekke. Dette er trajectory/flightline 3 i punktskydata. Analyse ble gjort på klasse 2 – Ground. Analyser startet isør og alle løpenummer går fra sør til nord. Koordinater for start og slutt av analysestrekning ble koordinert med georadaranalyse. Resultater av analyse er presentert som rapporter i Excel-format, vektorer i DGN- og DWG-format, samt klassifisert punktsky i LAS- og LAZ-format.

Start og slutt analysestrekning finnes i vektorfil i laget «00_Områdegrense».

4.1 Vektorisering

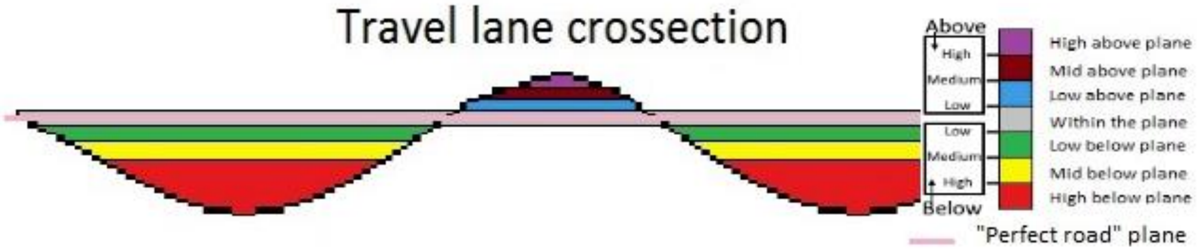
Som utgangspunkt for all veianalyse ble veimarkering vektorisert og kvalitetskontrollert. Dette definerer ytterkant og midt av vei i analyseområdet.

Vektorisering av veimarkeringer er presentert i vektorfil i laget «00_Nordgående veimarkeringer». Veianalysepolygon med ytterkanter fra områdegrense og kjørebanekant i laget «00_Veipolygon».

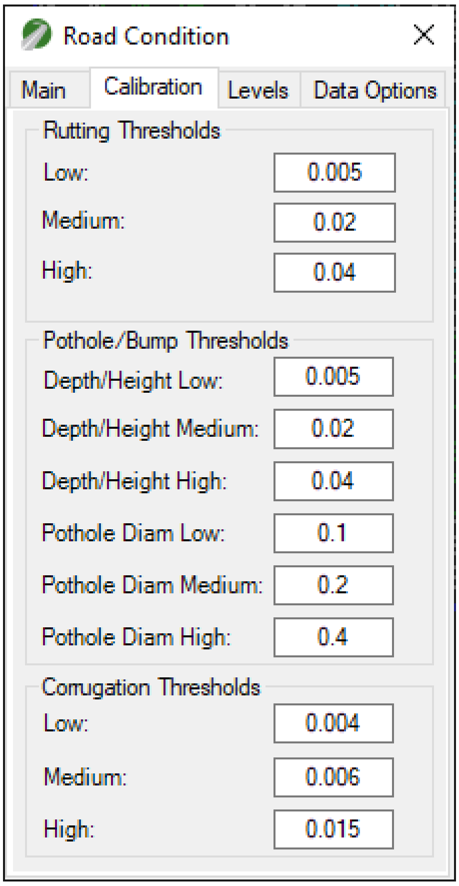
4.2 Hjulspor, hull, og tversgående ujevnheter

Med utgangspunkt i bakkeklasse og vektoriserte veimarkeringer fra nordgående kjøring ble veitilstand analysert i TopoDOT.

Dette verktøyet vil finne eventuelle hjulspor, vaskebrettmønster, hull, forsenkinger og forhøyninger i veibanen. Verktøyet analyserer hvert kjørefelt for seg, og klassifiserer punktsky etter avstand fra en ideell veioverflate. TopoDOT bruker en kombinasjon av kartlagt veimarkering og punktsky til analyse:



Grenseverdiene kan defineres selv, i dette prosjektet var grenseverdiene satt til følgende, samt tilhørende punktskyklasser:



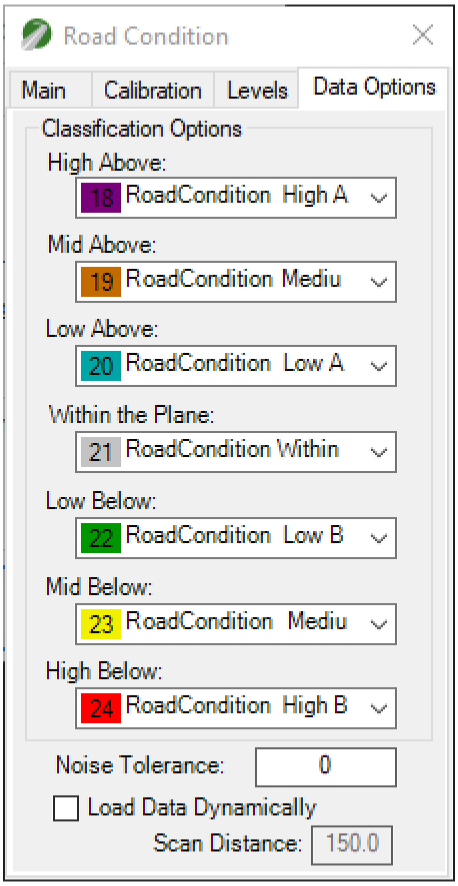
Road Condition

Main | Calibration | Levels | Data Options

Rutting Thresholds
Low: 0.005
Medium: 0.02
High: 0.04

Pothole/Bump Thresholds
Depth/Height Low: 0.005
Depth/Height Medium: 0.02
Depth/Height High: 0.04
Pothole Diam Low: 0.1
Pothole Diam Medium: 0.2
Pothole Diam High: 0.4

Corrugation Thresholds
Low: 0.004
Medium: 0.006
High: 0.015



Road Condition

Main | Calibration | Levels | Data Options

Classification Options
High Above: 18 RoadCondition High A
Mid Above: 19 RoadCondition Mediu
Low Above: 20 RoadCondition Low A
Within the Plane: 21 RoadCondition Within
Low Below: 22 RoadCondition Low B
Mid Below: 23 RoadCondition Mediu
High Below: 24 RoadCondition High B

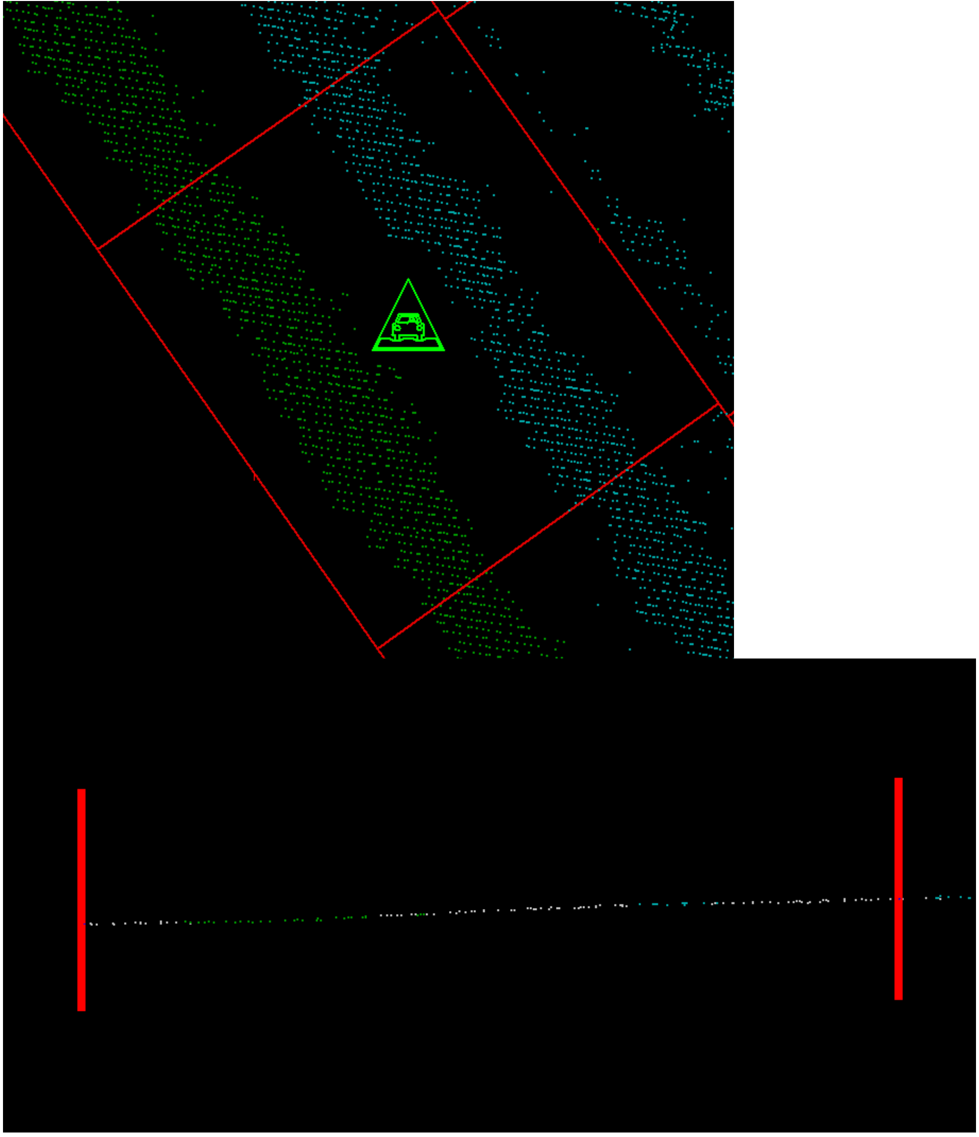
Noise Tolerance: 0
☐ Load Data Dynamically
Scan Distance: 150.0

Relevante handbøker fra SVV ble brukt til å sette verdier der det fantes en passende, tilsvarende verdi.

Punkter med gitt høyde/dybdeverdier kan deretter vektoriseres som punkter eller presenteres som georefererte rasterbilder hvis ønskelig.

I tillegg vil verktøyet dele kjørefelt inn i blokker på drøye tre meter. Blokkene vektoriseres og får tildelt en alvorlighetsgrad fra tidligere definerte grenseverdier og type avvik som vektoriseres med følgende symboler:

Nedenfor kan ses en blokk med hjulspor av lav alvorlighetsgrad til venstre, samt en forhøyning til høyre. Ovenfra og i profil:



Analysert punktsky, klassifisert etter grenseverdier, leveres i filen «50521_Borealis_analysert.las». Vektorer fra TopoDOT-analyse er presentert i vektorfil i lagene «01_Road Blocks» og «01_Severity Info».

4.2.1 Veianalyserapport

Veianalyse kan også skrive ut rapport med gjennomsnittsverdier for egendefinerte blokkstørrelser. I denne analysen er egendefinert blokkstørrelse 20 meter, som ønsket av SVV. Blokklengden er gjennomsnittlig, og ikke helt nøyaktig.

Det relevante som kan trekkes ut av denne rapporten er verdier på hjulsporvolum, gjennomsnittlig og maksimal dybde av disse, samt informasjon om andre typer ujevnheter i blokken. Det er også beregnet PCI, Pavement Condition Index, Deduct, Density, og andre verdier som relaterer til den amerikanske standarden ASTM 6433. Rapport gir også en vurdering av totaltilstand i en blokk, fair, satisfactory, etc.

Veianalyserapport leveres i filen «50521_Veianalyserapport.xlsx». Vektorer fra rapporten i vektorfil med lagene «02_Report Info» og «02_Sample Unit Bounds» som viser utstrekning på de cirka 20 meter lange blokkene.

4.2.2 Fall og stigning

Forberedelse av data til veianalyse er samtidig en forberedelse av data til analyse av tverrfall/takfall og stigning på veien og presenteres derfor som ekstra data for å vise muligheter i TopoDOT. Fall og stigning er også beregnet per kjørefelt. Fallverdier i prosent hver 5. meter der prosentverdi er negativ hvis kjørebanekant er lavere enn senterlinje. Linjer og verdier er vektorisert, samt skrevet ut som rapporter i Excel-format.

Vektorer av fall og stigning i vektorfil i lagene «03_Cross Slope Measurements», «03_Cross Slope Text», «03_Grade Measurements», og «03_Grade Text». Rapportfilene «50521_Fall_stigning_høyreFelt_nordover.xlsx» og «50521_Fall_stigning_venstreFelt_sørover.xlsx».

4.3 Langsgående ujevnheter og sprekker

TopoDOT har ingen støtte for analyse av langsgående ujevnheter. IRI og MPD krever utstyr som vi har montert på vårt Viatech-system, ikke Lynx.

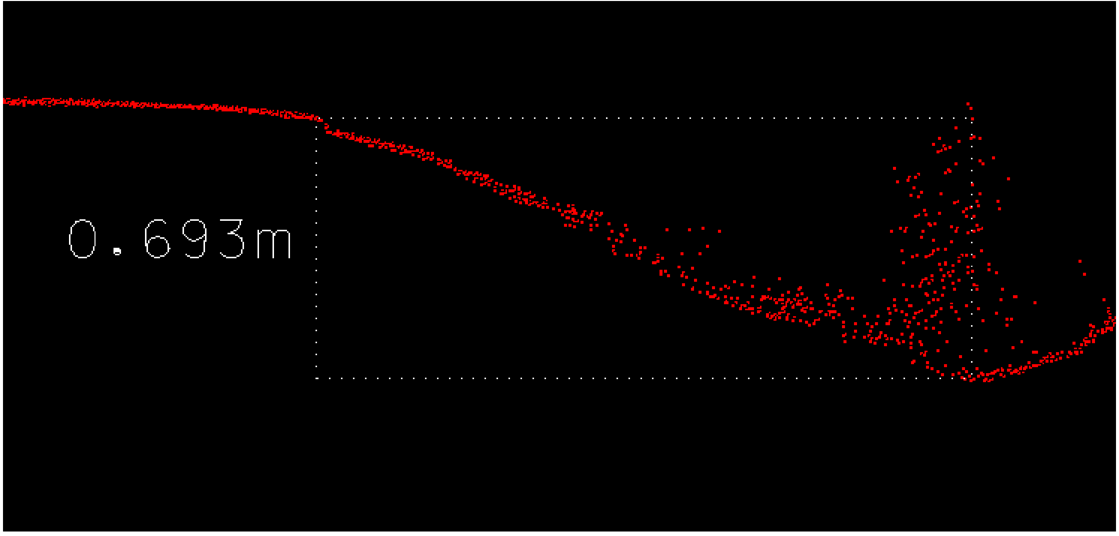
Sprekkdeteksjon kan gjøres fra geometri og/eller intensitetsverdier i en punktsky. Terratec har god erfaring med å detektere større sprekker ved bruk av Viatech-punktsky, Lynx har erfaringsmessig vist seg å være for støyete, samtidig vil selv små unøyaktigheter i scannerkalibrering påvirke sprekkdeteksjon negativt. Fuktig overflate dagen det ble kjørt har gjort sprekker vanskeligere å se i intensitet, samtidig som det har gjort punktsky litt mer støyete enn normalt. Det ble gjort forsøk å detektere sprekker i denne analysen, men resultatet var for støyete.

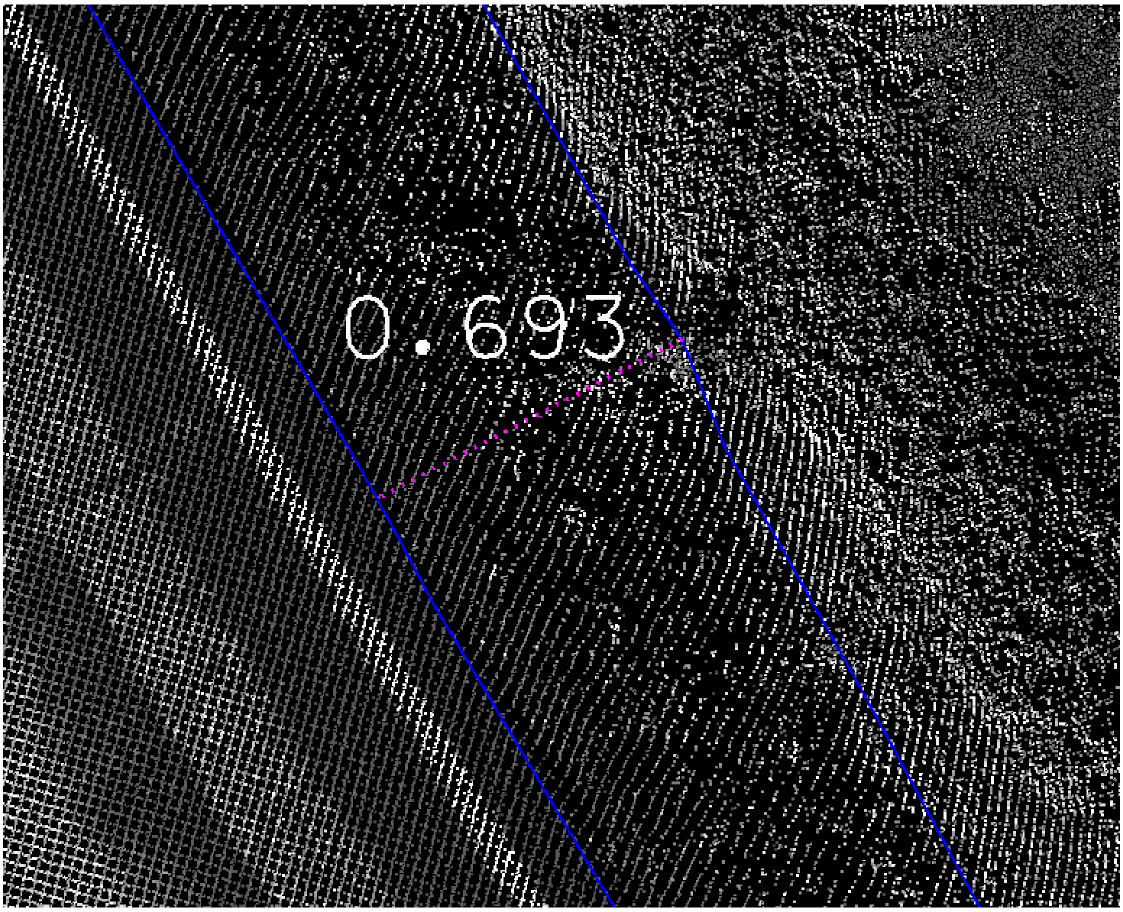
Med vårt Lynx-system kan vi produsere 360°-panoramabilder, hvilket vil bli presentert i Urbex. Med dette vil det være enkelt å se gjennom bilder og gjøre en visuell sprekkinspeksjon.

4.4 Vannavrenning

Med nåværende metoder vil asfaltkant og grøftebunn begge kartlegges manuelt fra punktsky. Viatech med en enkelt høypresisjonscanner på tvers av kjøreretningen vil gi en veldig presis punktsky på veibanen til veianalyse. Lynx, med to skråstilte scannere vil gi mer innsyn bak objekter, og under vegetasjon. En grøftebunn helt uten vegetasjon vil kunne kartlegges like nøyaktig fra begge systemer, der det er vegetasjon vil Lynx' to skrå scannere penetrere bedre og gi mer nøyaktige grøftedybder.

Kartlagt asfaltkant og grøftebunn kan deretter prosesseres i GIS-programvare, for eksempel FME, hvor høydedifferanse kan beregnes og presenteres i gitte intervaller. Eksempel under i profil og ovenfra.





Eksempel på manuelt kartlagt asfaltkant, grøftebunn, og grøftedybder finnes i vektorfil i lagene «04_Asfaltkant», «04_Grøftebunn», og «04_Grøftedybde».

5 Georadar prosessering

5.1 Personell

Følgende personell har vært ansvarlig for prosesseringsarbeid:

Tobias Jokisch	Prosessering og tolkning
Henrik Rinne	Produktgenering og kvalitetssikring

5.2 Programvare

Følgende programmer har vært brukt til behandling av data i prosjektet:

Programvare	Versjon	Anvendelse
Examiner	3.02	GPR prosessering / tolkning
SeismiGraphix	1.4.0	SEG-Y QC
FME	2018.1	Generering av produkter

5.3 Prosessering

For å kunne tolke dataene må rådata fra GPR prosesseres først. Prosesseringen omfattet:

- Set Time ground
- Interference suppression
- Inverse Selected Discrete Fourier Transform (ISDFT)
- Background Removal (BGR, 2 passes)
- Gradual low pass filter (in time)
- Gradual low pass filter (spatial)

5.3.1 Time ground

GPR antennen beveger seg opp og ned i samsvar med små dumper i veien. Dermed endrer seg høyde over bakken bestandig. Dette kompenseres ved at første refleksjon etter den direkte bølgen blir plukket og hele trasen skiftet med tilsvarende tid. Ny korrigert time ground ble satt til 3.7ns, dermed forblir den direkte bølgen synlig i dataene.
Denne korreksjonen vil også korrigere for skjevheter i antennen på tvers av kjørebanen. Alle dybder i leveransen referer til veioverflaten.

5.3.2 Interference suppresion

Interferens i dataene blir undertrykket ved en automatisk interference suppression (threshold-based).

5.3.3 Inverse Selected Discrete Fourier Transform

Dataene overføres fra frekvensdomene til tidsdomene. Samtidig dempes høye frekvenser med økende tid slik at resultat blir mindre støyete.

5.3.4 Background removal (BGR)

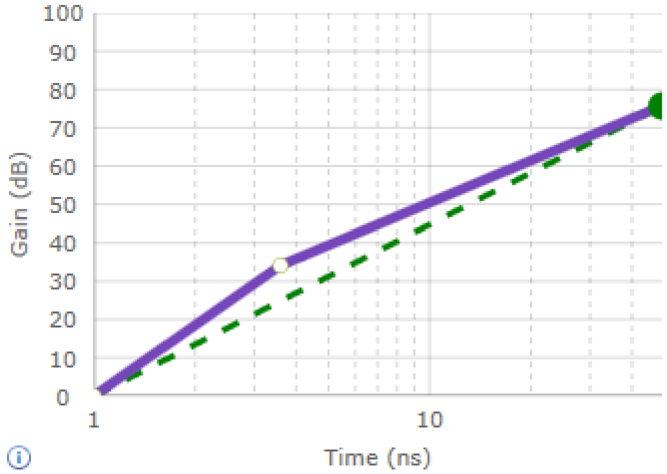
Background removal blir gjennomført i to steg. Første steg er en relativ mild fjerning av bakgrunn støy med en sliding mean filter på 200m lengde. Starttid for dette filteret er 3.7ns (taper på 1ns, full on på 4.2ns).
Andre steg er et sterkere filter som anvendes først fra 10.5ns med en taper på 5ns (full on på 13ns).

5.3.5 Gradual low-pass filter

Inkoherent resterende støy blir fjernet med en low-pass filter i tid og en low-pass filter i x og y. Filterlengde er frekvensavhengig.

5.3.6 Gain

Dataene ble forsterket med følgende gain funksjon:



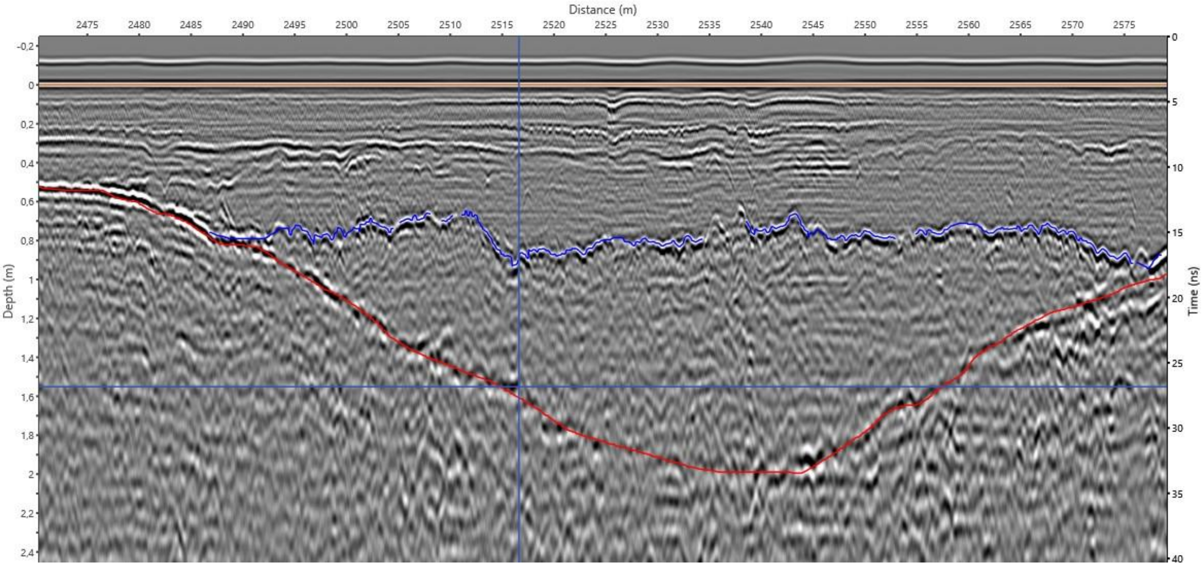
Figur 4: Gain funksjon brukt på dataene

5.4 Dybdekalibrering

Dataene ble dybdekalibrert ved kjerneprøver og prøveboringer foretatt etter innsamlingen. Det ble foretatt 7 boreprøver fordelt på hele veistrekningen. Resultatet fra disse ble så sammenstilt med resultatet fra tolkningen for å bestemme den dielektriske konstanten i undergrunnen ved de ulike lokasjonene. Resultat fra boreprøvene er asfalttykkelse (total tykkelse veidekke) og dybde til fjell (der påtruffet). Det finnes ingen informasjon om tykkelse på ubundne bærelag.
Ved de fleste lokasjonene ligger fjellet for dypt til å kunne synes på radardataene som har en innsamlingslengde på 50ns tilsvarende ca. 3m.
Asfalttykkelsen korrelerer derimot godt med de fleste boreprøvene, men borepunkt 18600m, som er startpunkt for delstrekningen som skulle tolkes, er et unntak. Den sterke refleksjonen som ble tolket som asfaltens underkant impliserer en svært høy epsilon-verdi. Den er likevel ikke usannsynlig høy hvis asfalten er porøs og mettet med vann. En annen mulighet er at bunn asfalt ikke er synlig og at den tolkede grenseflaten tilsvarer bunn ubundne bærelag.
En oversikt over boreresultater finnes i tabell på neste side.

Fra borerapport				Fra GPR resultat	
Hullnr. (m hp1)	Dybde til fjell (m)	Dybde boret i fjell	Asfalttykkelse (cm)	Fjell	Asfalt
910	2.04	3.05	5,5	ikke synlig	Epsilon: 5
2480	1.68	0.61	13,5	fjell synlig, epsilon=5	Epsilon: 5.5
9520	13.40!!	0.0	13	N/A	Epsilon: 5.5
18600	3.08	1.33	15,5	fjell for dypt	Epsilon: 11 - 20
20600	5.48!!	0.0	15	N/A	Epsilon: 6.5
25420	10.56	4.89	18	fjell for dypt	Epsilon: 6.5-7
33000	2.80	0.69	16,5 (23)	fjell ikke synlig	Epsilon: 6.5
37260	1.52!!	0.0	16,5	fjell muligens synlig	Epsilon: 4,5 - 7

Georadarbildet ved borehull no. m2480 vises i Figur 5.

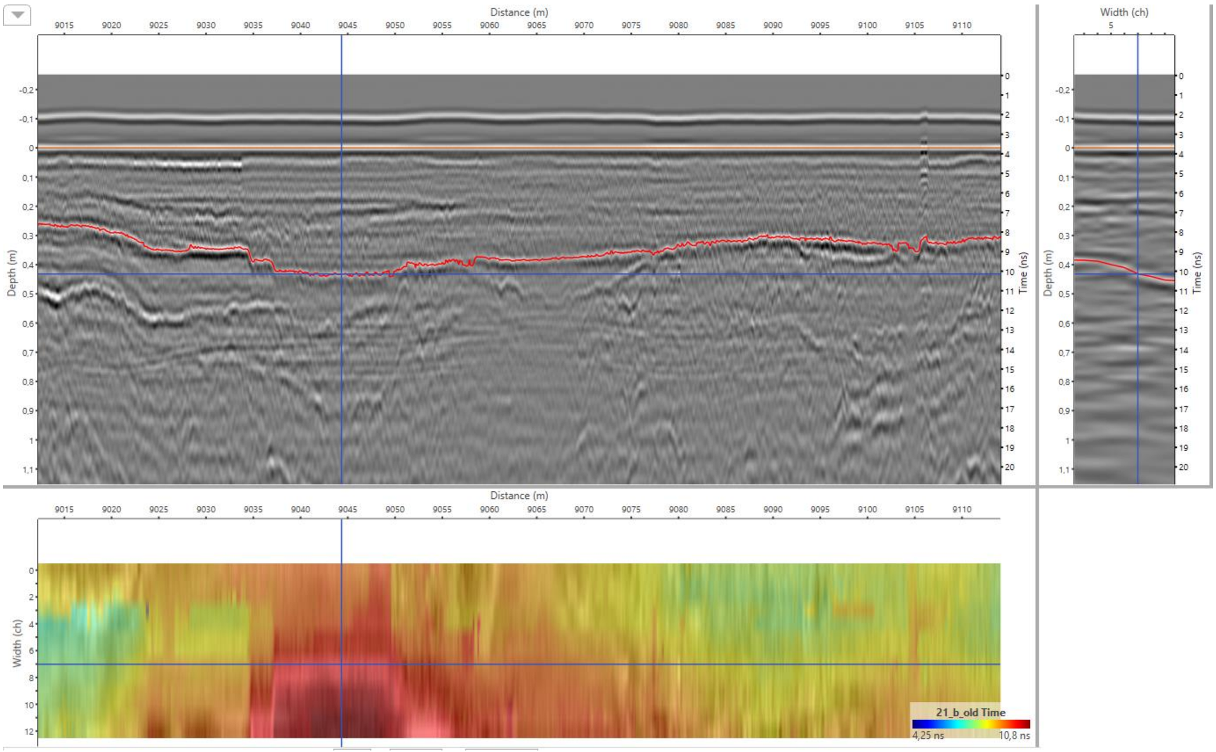


Figur 5: Borehull m2480. Trådkorset viser posisjon og dybde til fjell. Den røde horisonten er dermed fastfjell, topp morene er i blå.

6 Georadar tolkning

6.1 Generelt

Tolkningen er i det store og hele konsistent mellom begge felt. Det finnes derimot en del variasjon på tvers av veibanen, særlig i søndre delen som viser at veioppbyggingen ikke er homogen. Et eksempel vises i Figur 6.



Figur 6: Radargramm både langs vei og på tvers av veien (oppe) og dybdeskive (nede) med fargelagt dybde til bunn asfalt.

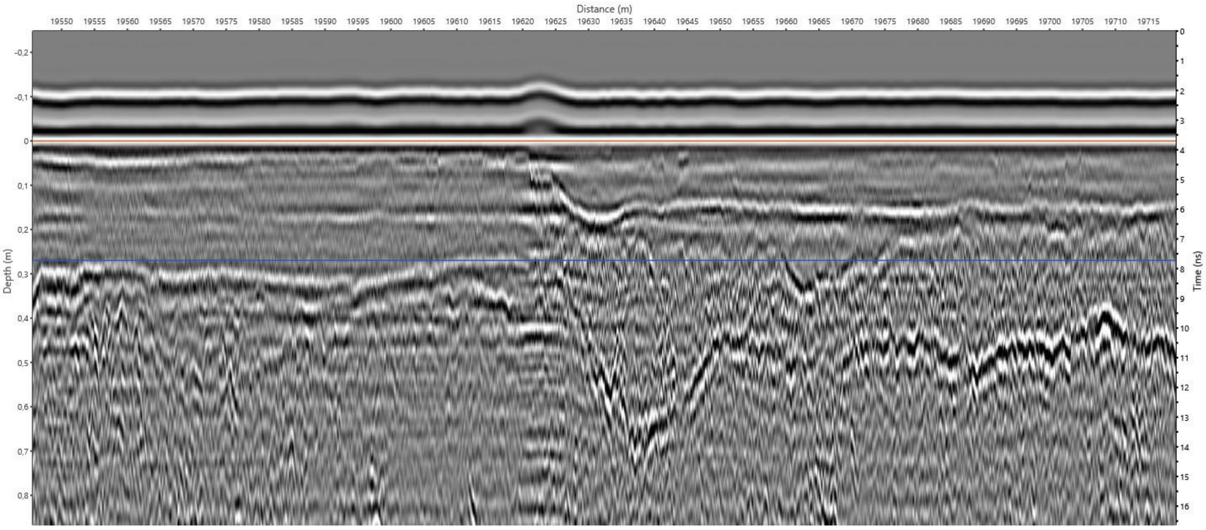
Tolkningen ble gjennomført i 3 steg. I første omgang ble strukturene tolket semiautomatisk (manuell plukking av sterke refleksjoner kombinert med automatisk tracking basert på krysskorrelasjon). Små hull i tolkningen ble interpolert i 3D (x, y og z). Større hull i tolkningen ble tolket manuell dersom refleksjonen fortsatt er svak synlig / grenseflaten virker rimelig. Hvis usikkerheten ble for stor eller horisonten ikke er synlig på større arealer ble det ikke tolket noe. Bunn slitelag / bunn asfalt er i det store og hele godt synlig, med lite behov for interpolasjon. Disse ble derfor vurdert med kvalitet=1. De andre lag ble i større grad interpolert og manuell tolket. Områder som ble interpolert ble tildelt kvalitet=2, områder som ble manuell tolket kvalitet=3.

Alle radargrammene som vises i rapporten har en dybdeskala basert på epsilon=5. Det er altså ikke verdien som ble brukt i dybdekalibreringen. I beskrivelsen vises det derfor bare til to-vei-tid (TVT) i [ns].

Beskrivelsen av tolkningen som følger nedenfor refererer til gammel vegreferanse (m hp1) mens leveransen av tolkningen er i henhold til ny vegreferanse (hp5).

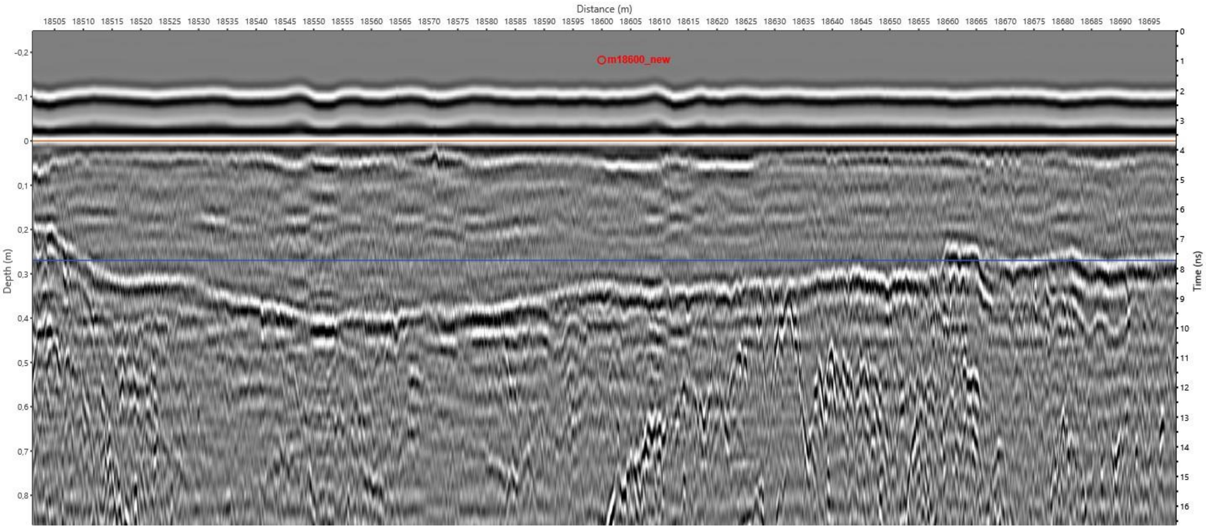
6.2 Bunn slitelag / bunn bundne lag (Kode 21a / 21b)

En 2km lang delstrekning ble tolket som går fra m18600 til m20600 (hp1, gammel veireferanse). I midten av denne strekningen er overgang fra gammel til rehabilitert/ny vei godt synlig (se Figur 7).



Figur 7: Radargram rundt m19600. Overgang fra gammel til ny vei er godt synlig

Mens asfalten på den nye strekningen korrelerer godt med boreprøven (s.o., Figur 9) er det usikkerhet rundt tolkningen av bunn bundne lag på den gamle strekningen. Borekjernen fra m18600 viser en todelte veidekke. De øverste 5cm kan tilsvare re-asfaltering. Et lagskille mellom det øverste laget og det tykkere nederste laget er også synlig i georadar-resultatet (se Figur 8). Denne grenseflaten ble derfor tolket som bunn slitelag (21a). Det er usikkerhet rundt bunn veidekke (21b) som enten kan være usynlig i radardataene eller havne lengre ned pga. høyere vanninnhold i asfalten (Figur 8).



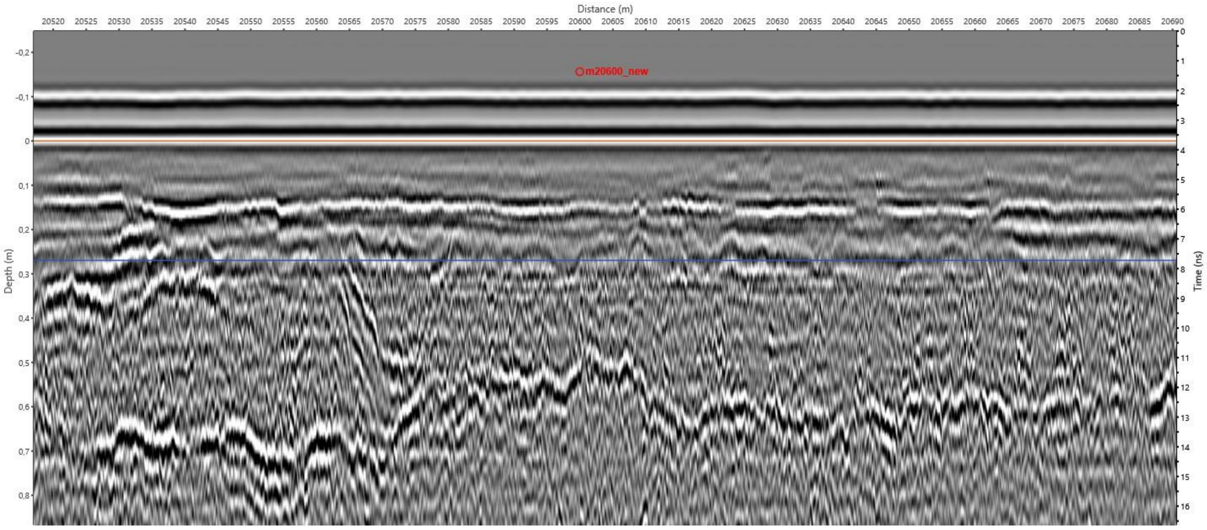
Figur 8: Radargram rundt borepunkt m18600. Øverste refleksjon er den direkte bølgen fulgt av overkant asfalt (3.7ns). Bunn slitelag kommer kort etter. Bunn asfalt forventes egentlig mellom 5-6ns, men kommer først etter 7+ns. Det er derfor ikke sikker om dette er bunn asfalt eller et annet lagskille.

6.3 Bunn ubundne bærelag (Kode 41)

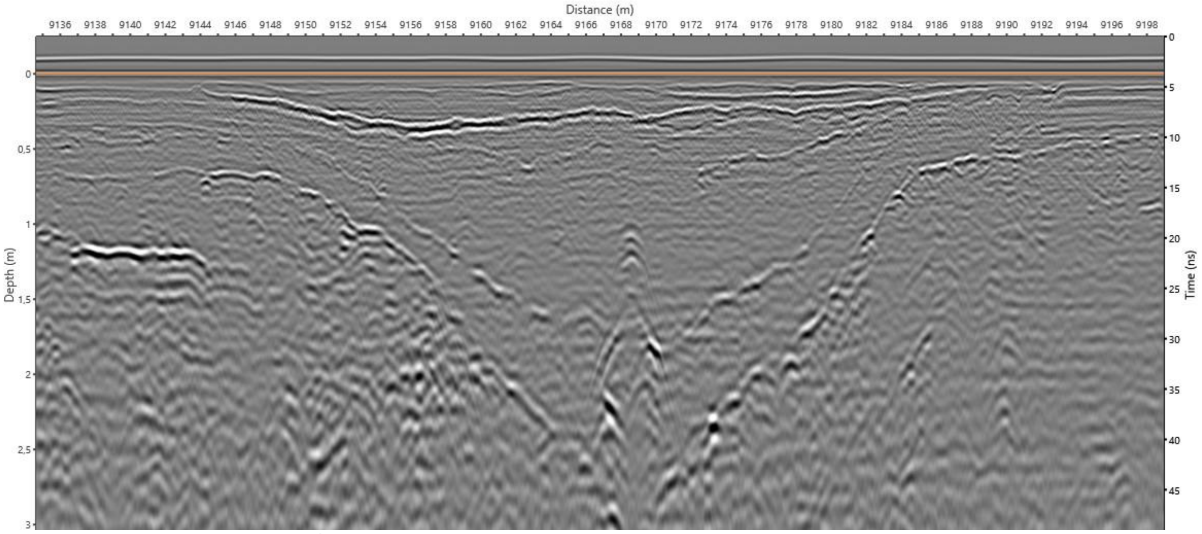
Bunn av de ubundne lag har blitt tolket med utgangspunkt i tolkningen av bunn overbygning (kode 71). Det kan ikke sies med sikkerhet at den grenseflaten tilsvarer bunn ubundne lag og lagtykkelsen varierer veldig. I den rehabiliterte strekningen er denne grenseflaten ikke blitt tolket bortsett fra et mindre område.

6.4 Bunn overbygning (kode 71)

Bunn overbygning er stort sett veldig tydelig i nordre delen (ny/rehabilitert vei, se Figur 9). Lagtykkelsen er i samme størrelsesorden på hele strekningen. I søndre delen (gammel vei) viser tolkningen en mer variert lagtykkelse. I tillegg vises det fordypninger i strukturen som kan være grøfter for kulverter (eksempel vises i Figur 10). Disse er forholdsvis dype (2-3m) og frekvensinnholdet er dermed betydelig lavere i disse områdene.



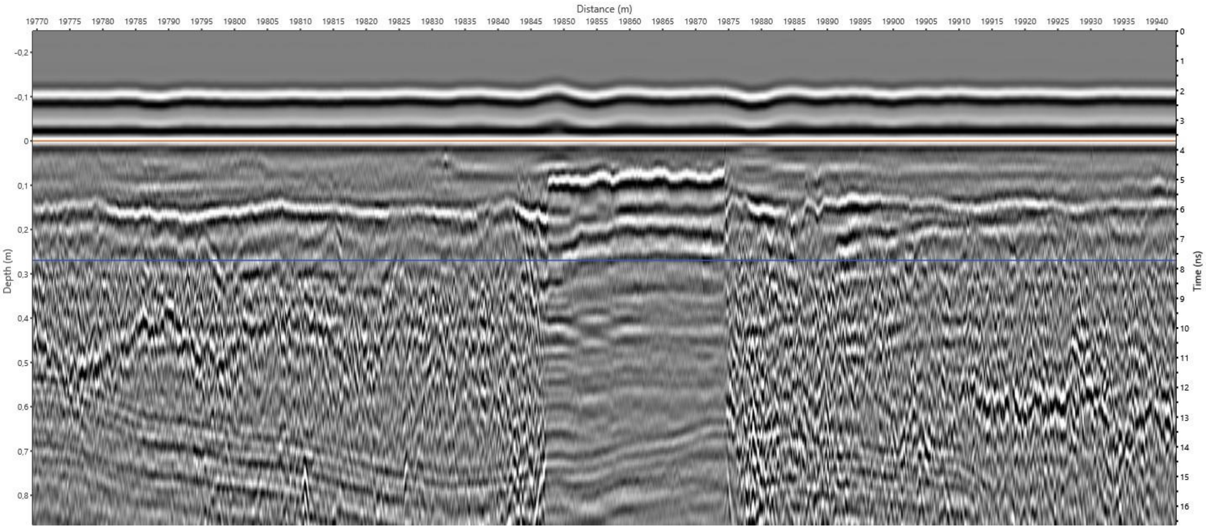
Figur 9: Radargram rundt borepunkt 20600



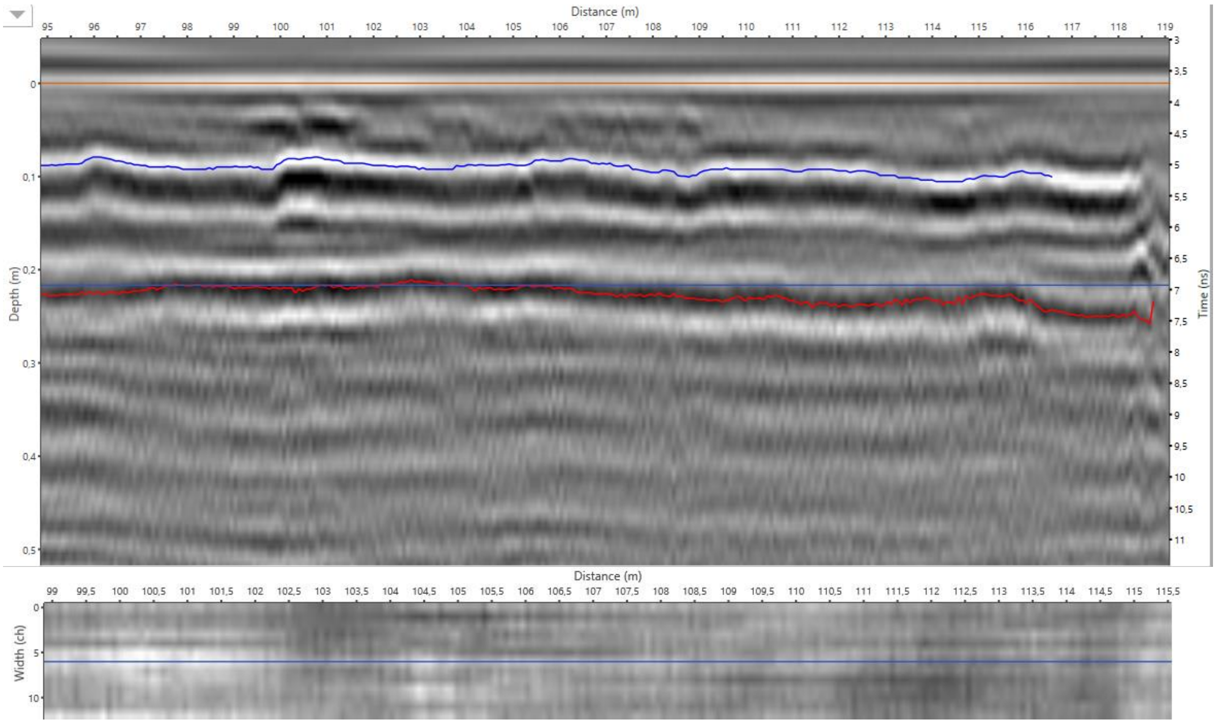
Figur 10: Innskjæring / grøft med mulig kulvert

6.5 Bro

Den ene broen på den to km lange strekningen skiller seg godt ut på georadarresultatet. Dataene kan brukes til å kartlegge posisjon til armeringen og overdekning med armering i samme sleng, noe som er fordel ved bruk av en 3D antenne (Figur 12).



Figur 11: Radargram rundt m19860. Den høyfrekvente støyen rundt 15ns er interferens som skyldes rekkverk ved siden av veien.



Figur 12: Detalj bro. Oppe viser vertikal profil med topp asfalt (oransje), bunn asfalt (blå) og topp armeringsjern (rød). Nede vises dybdeskive gjennom armeringen

7 Leveranse

Etter kundenes ønske leveres det bare en av de 13 kanaler, den som dekker høyre hjulspor. Dataene leveres prosessert i SEG-Y format som er et vanlig format for seismiske data og GPR data. Informasjon om byte posisjoner er lagt i 7.3. Dataene kan leses i bl. a. RoadDoctor.
Rådataene og prosesserte data i 3dradar-format oppbevares hos Terratec i 5 år og kan ved behov leveres. Rådata i .3dra format kan også leses og prosesseres i RoadDoctor.
Tolkningen leveres i .dwg format (relativ dybde). For en enkel visualisering leveres georefererte tiff-bilder i innsynsløsningen BlomUrbex som også kan brukes til å visualisere 360graders bilder som ble tatt under innsamlingen.
Ut over det leveres tolkning i høyre hjulspor i excel-ark som benyttes av Statens Vegvesen. Dybdene angis i 10m intervaller. Veireferansen som brukes i BlomUrbex og excel-arket er den nye (hp 5).

7.1 BLOM Urbex

Tolkning av georadardataene leveres også gjennom Terratec sin innsynsløsning BLOM Urbex.

http://www.blomurbex.com/maps/index.html
Bruker: SVVrs
Passord: R83x8

Blom Urbex er en webbasert innsynsløsning til visualisering av ortofoto, 360graders Bilder og farge-kodete kart som viser variasjonen av lagtykkelsen i planet. Det er mulig å koble Blom Urbex til informasjonen fra excel-arket som tolkningen leveres i.

7.2 Filstruktur.

Dataene er levert på FTP i følgende mapper

Analysedata	Resultater av veianalyse som beskrevet i rapport. Vektorer på DGN og DWG-format, punktsky på LAS og LAZ-format, rapporter på Excel-forma
Punktsky	Klassifisert, matchet og sammenslått punktsky på LAZ 1.2-format med prosjektfil og blokkinndeling på DGN-, DWG-, og PDF-format.
SEG-Y	Georadardata (høyre hjulspor) i SEG-Y format
DWG	Tolkning i .dwg format (3D punktsky)
EXCEL	Tolkning (høyre hjulspor) i excel-ark
Rapport	Denne rapporten
BlomUrbex	Tolkning (høyre hjulspor) i .geojson format (kan leses i Blom Urbex), Fargeskala i .pdf format

7.3 SEG-Y data

SEG-Y dataene er i rev01 format. Prosesseringssekvensen er nærmere beskrevet i avsnitt 5.3.
To filer er levert via FTP:

2019-08-20-006.sgy	Sørgående felt
2019-08-20-007.sgy	Nordgående felt

7.3.1 EBCDIC Header

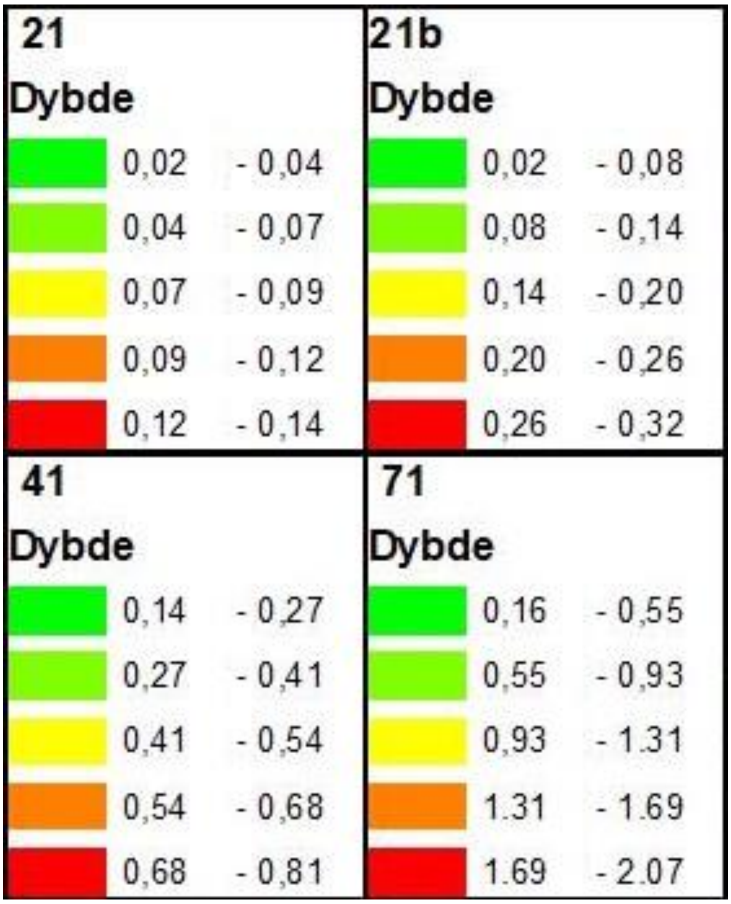
```
C 1 Created: 3D-Radar Examiner (Wednesday, 23 October 2019 11:49:19)
C 2 Volume: X-lines: 478154, In-lines 1, Samples: 503
C 3 CRS: EPSG:32634, scale factor 0.01
C 4
C 5 Byte positions (in addition to REV. 1 standard positions):
C 6 X-coordinate = 73-76
C 7 Y-coordinate = 77-80
C 8 In-line = 9-12
C 9 X-line = 13-16
C10
C11 Sample intervals (e.g. 117 and 3217) are given in picoseconds
C12
C13
C14 1/1 = (471915.1, 7696127.08)
C15 1/2 = (471915.06, 7696127.02)
C16 2/2 = (471915.12, 7696126.96)
C17
C18
C19
C20
C21
C22
C23
C24
C25
C26
C27
C28
C29
C30
C31
C32
C33
C34
C35
C36
C37
C38
C39 SEG Y REV1
C40 END TEXTUAL HEADER
```

7.3.2 Trace Header (byte posisjoner)

JOB_ID_NO	1.0
SAMPLE_RATE	97.0
SAMPLE_RATE_FIELD	97.0
NSAMPLES	503.0
NSAMPLES_FIELD	503.0
FORMAT_CODE	3.0
SEGY_FORMAT_REVISION_NO	256.0

1	TRACE_SEQ_NO	23
5	TRACE_SEQ_REEL	1
9	FIELD_RECORD_NO	1
13	CHANNEL_NO	0
71	COORD_SCALER	-100
73	XSHOT	47191657
77	YSHOT	769612591
115	NSAMPLES	503
117	SAMPLERATE	97
183	SHOT_SEQUENCE_NUMBER	375991775
185	FIELD_STATION_NUMBER	769612591

7.4 Fargeskala brukt i BlomUrbex



21

Dybde

🟩	0,02	- 0,04
🟩	0,04	- 0,07
🟨	0,07	- 0,09
🟧	0,09	- 0,12
🟥	0,12	- 0,14

21b

Dybde

🟩	0,02	- 0,08
🟩	0,08	- 0,14
🟨	0,14	- 0,20
🟧	0,20	- 0,26
🟥	0,26	- 0,32

41

Dybde

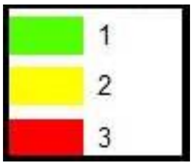
🟩	0,14	- 0,27
🟩	0,27	- 0,41
🟨	0,41	- 0,54
🟧	0,54	- 0,68
🟥	0,68	- 0,81

71

Dybde

🟩	0,16	- 0,55
🟩	0,55	- 0,93
🟨	0,93	- 1.31
🟧	1.31	- 1.69
🟥	1.69	- 2.07

Figur 13: Fargeskala for lag i Blom Urbex. Slitelag (21), Bunn bundne lag (21b), Bunn ubundne bærelag (41), bunn overbygning (71)



🟩	1
🟨	2
🟥	3

Figur 14: Fargeskala for kvalitet (41 og 71)

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