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INNOTRACK

Integrated Project (IP)

Thematic Priority 6: Sustainable Development, Global Change and Ecosystems

D1.4.7 Data Mining of Data Sets

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Dissemination Level		
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Glossary

Please provide a description of all acronyms/abbreviations used in the document.

Abbreviation/acronym	**Description**
TRV	Track recording vehicle
IM	Infrastructure manager

1. Executive Summary

Large volumes of data from track recording vehicles containing information about many aspects of track geometrical features are available. The data sets available within Innotrack have been studied with the aim of determining whether comparisons of minor misalignments may be made between sections of track with similar geometric characteristics. In particular, the lateral alignment data has been analysed with the intention of identifying sections of track where defects may have become embedded in the track due to the consistent hunting motion of rail traffic.

Recent investigations into the causes of rolling contact fatigue (RCF) on the UK network studied several sections of track on which patches of RCF separated by an approximately constant distance were observed [1]. It is suggested that these patches may be caused by dynamic forces resulting from lateral misalignments within the track due to the kinematic behaviour of wheelsets. These lateral misalignments may be within current maintenance standards, leading to questions over whether current standards should be modified to increase asset lifetime.

2. Introduction

Railways are extremely large assets about which huge volumes of data can be gathered. Track recording vehicles (TRVs) regularly collect data which provides accurate information on many aspects of track geometry which is essential for the planning and scheduling of track maintenance. Amongst the parameters that are measured by the TRV are the track lateral and vertical alignment, gauge and curvature. The data can be used to identify track irregularities which require immediate or urgent maintenance.

This deliverable calls for data mining of data sets. The availability of data sets gathered by track recording vehicles from several of the IMs participating in Innotrack provides the opportunity to analyse and compare track geometric features.

Studies of UK track have observed patches of RCF which occur periodically [1]. It has been proposed that this pattern of RCF may have been caused by dynamic forces on track containing lateral misalignments related to the kinematic oscillations of vehicles.

It is therefore of interest to study the lateral alignment data provided by both UK and several other Innotrack infrastructure managers with the aim of identifying and comparing lateral misalignments with a consistent wavelength which may be related to this phenomenon.

2.1 Klingel equation

Due to the inherent instability of axles, rail vehicles experience lateral oscillations along the track. This type of motion is known as hunting. An equation for the hunting motion of a single wheelset was solved by Klingel in 1883 which shows that the wavelength of the oscillation is a function of wheel conicity, track gauge and wheel radius. It is proposed that when hunting motion consistently occurs along a section of track, set off by a small defect for example, then the track may become permanently deformed by the oscillations becoming embedded in the track.

The Klingel wavelength, L_k, is given by

$$L_k = 2\pi\sqrt{\frac{rs}{2\gamma}}, \qquad \textbf{\textit{(1)}}$$

where r is the medium rolling radius, s is the distance between points of contact and γ is the conicity of the wheelset. The Klingel wavelength is dependent only on the geometrical properties of the wheels and track. Figure 1 shows the parameters of equation 1 for a single wheelset with purely conical wheels.

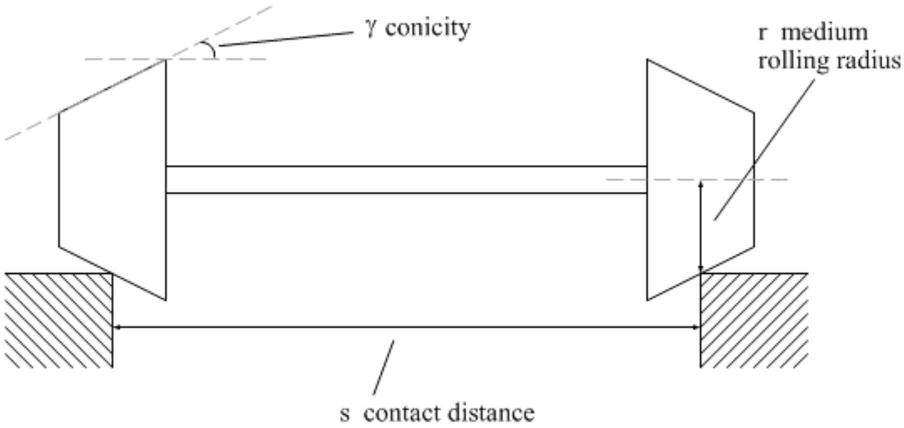


Figure 1

Figure 2 shows the effect of varying the parameters in equation 1 on the Klingel wavelength. It is a plot of Klingel wavelength against contact distance for various conicity values with a constant radius of 0.5 metres.

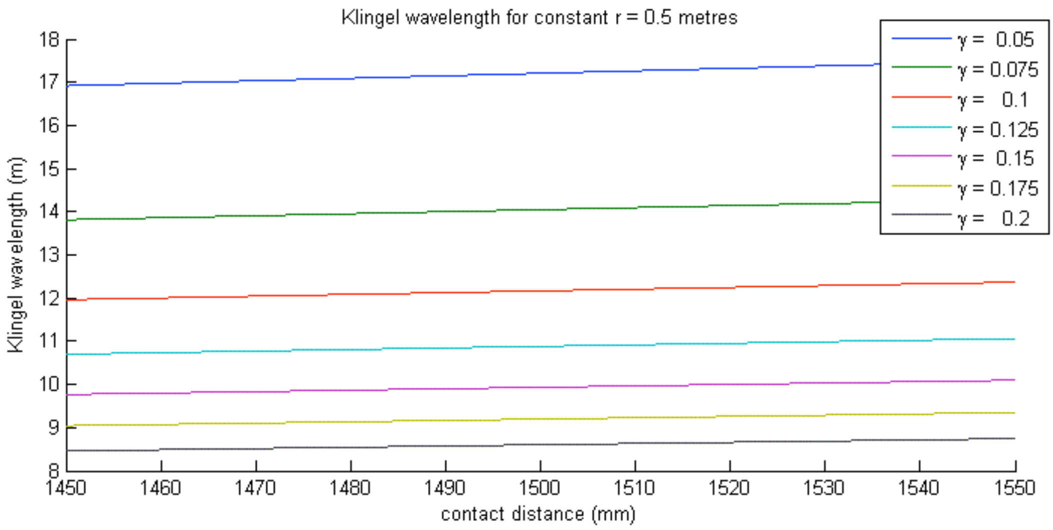


Figure 2

3. Track recording vehicle data

In INNOTRACK, track geometry data has been received from the following six national infrastructure managers (IMs).

• Network Rail (NR) - United Kingdom

• ProRail - Netherlands

• Deutsche Bahn (DB) - Germany

• Banverket (BV) - Sweden

• Österreichische Bundesbahnen (ÖBB) - Austria

• Société Nationale des Chemins de fer Français (SNCF) - France

Table 1 gives a summary of the data received from each of the infrastructure managers. It shows the length of track for which TRV data is available and this length as a percentage of the total track within the country. It also shows an approximate average value for the distance between measurements for each IM. For all but one of the IMs, the inter measurement distance is about 20 centimetres. The distance between measurements in the data provided by the SNCF is, however, 10 metres.

IM	Km of data	Total track km	Percentage of total	Inter-measurement distance
NR	4600	19568	23.5%	0.20 m
DB	650	34128	1.9%	0.16 m
ÖBB	505	5702	8.9%	0.25 m
BV	217	9957	2.2%	0.25 m
SNCF	1599	29547	5.4%	10.0 m
ProRail	230	2776	8.3%	0.25 m

Table 1

Track recording vehicle data is given for the following lines:

- Network Rail: 36 different files - see Annexe
- Deutsche Bahn: Hannover – Würzburg, Würzburg - Hannover
- ÖBB: Wörgl – Zell am See – Salzburg, Salzburg – Linz – Vienna
- Banverket: Line 111: Kiruna mbg – Riksgränsen, Line 119: Boden C – Luleå, Line 810: 1km of data only, at Mjölby, Line 910: Hässleholm - Höör
- SNCF: Paris – Bordeaux, Paris - Lille
- ProRail: Eindhoven – Weert, Eindhoven – Roermond, Asra – Leiden

3.1 Parameters given by infrastructure managers

The lateral alignment parameter is to be used in this analysis. There are several columns of data corresponding to lateral alignment given by each IM in each TRV data file. In some cases data corresponding to the left and right rails may be given separately, and in others an average for both rails is provided. NR, DB, ÖBB and BV apply different filters to the raw TRV data giving several sets of data for alignment in each data file. This information is indicated Table 2. Note that for ProRail no data corresponding to lateral alignment was provided.

IM	**Alignment**
NR	< 35 m average, < 70 m average
DB	< 50 m left, < 50 m right
ÖBB	short left, short right, < 70 m left, < 70 m right
BV	1-25 m left, 1-25 m right, 25-100 m left, 25-100 m right, 100-140 m left, 100-140 m right
SNCF	left and right
ProRail	not given

Table 2

3.1.1 Exclusion of SNCF and ProRail from the analysis

Defects in track geometry due to rail vehicles oscillating at the Klingel wavelength are expected to have wavelengths of the order of 10 metres, as can be seen in Figure 2. It is therefore unlikely to be possible to observe any such defects within the SNCF data, since the distance between data points in the data provided is 10 metres. For this reason, the SNCF track recording vehicle data will be excluded from this analysis. Since track recording vehicle data relating lateral alignment was not provided by ProRail, Dutch track is also excluded from further analysis here.

In the remainder of this report only the TRV data from Network Rail, Deutsche Bahn, ÖBB and Banverket will be considered.

3.2 Pre-processing of data

The TRV data files received from the IMs are saved in the format shown in columns 2 and 3 of Table 3. The first step in the pre-processing of the data is to convert the files into .mat format since Matlab will be used to perform the analysis. Files containing greater than 1.5 million rows of data are split into two .mat files since this appears to be about the limit of data that can be dealt with by Matlab at one time. From columns 4 and 5 of Table 3 it can be seen that both DB original data files were split in two and saved as 4 .mat files. Five of the original NR files were also split into two, resulting in 41 NR files.

IM	**Saved as format**	**Variable format**	**Original number of files**	**Number of .mat files**
NR	.csv and .dtf	comma separated	36	41
DB	.txt	tab separated	2	4
ÖBB	.txt	comma separated	2	2
BV	.txt	comma separated	5	5

Table 3

3.2.1 Standardisation of data format

The next steps in the pre-processing are to convert the data relating to the parameters used in this analysis into a standard format, as described in the following subsections.

Location information

Data representing the location at which each measurement is taken is converted if necessary to be a measurement in metres.

Radius

For each IM a parameter describing either the track's instantaneous curvature or its radius at each measurement point is provided. This information is standardised as a radius measurement in metres for each of the IMs.

Alignment

Several variables relating to track lateral alignment are provided by each of the IMs. Alignment parameters provided by the IMs may describe the lateral alignment of the left or right rail or the average of both and has been filtered using different filters. The alignment data has been converted if necessary to have units of millimetres, and where data has been given for the left and right rails separately, the average has been taken.

3.2.2 Irregularities in the data

Discrepancies in route location

There are occasional gaps in the route location information where the recorded distance between measurement points is significantly different from the usual inter-measurement distance. Therefore, within each TRV data file, the data is divided into sections; a new section begins whenever an inter-measurement distance of greater than 1 metre is recorded. Analysis then takes place within the sections.

Missing information in the ÖBB files

When information is missing in the ÖBB files, for example, if the TRV stopped recording due to low speed, a value of 99999 is recorded. These values are changed to an alignment value of zero. Since there are very few such cases, this has no significant effect on the analysis.

4. Segmentation

The TRV data was provided to the University of Birmingham by Corus [2]. An initial segmentation of the data has been carried out by Corus based on the radius of the track. Degradation of the track occurs at different rates depending on factors such as the loading, track geometry and structure. The segmentation aims to allow the identification of patterns of degradation within sections of track of similar geometry. The data received at the University of Birmingham appears to be in an unprocessed format, before any segmentation has taken place. Segmentation into curved and straight sections of track has again been carried out here, following the method used by Corus. It is described in the sections below.

4.1 Straight sections

Curvature measurements may take both positive and negative values. Positive curvature values are defined to be either curves to the left or right and negative values represent curves in the other direction. A perfectly straight section of track theoretically has zero curvature and an infinite radius. Track which is almost straight may record both positive and negative values close to zero. This in turn causes the calculated radius value to switch between large negative and large positive values. In order to deal with this phenomenon and the large calculated radius values of straight track, a ceiling of 6000 metres is applied. The modulus of any radius value which is greater than 6000 metres is considered to be a measurement corresponding to straight track.

Curvature and calculated radius measurements for an 8 km section of Network Rail track are shown in Figure 3. Any calculated radius value greater than 6000 metres or less than -6000 metres has been redefined as 6000 metres. This piece of track begins with a curve to the left or right of just over 1 km in length, followed by a transition to a curve in the other direction of approximately 2 km in length. There is then a transition to a straight section of track of 3 km followed by a transition to another curved section of track.

Once the straight sections of a file have been identified, the final step is to select only those which are longer than 100 metres in length. Any shorter sections are not considered as straight sections in this analysis and will be combined into transition sections once sections of constant curvature have been selected.

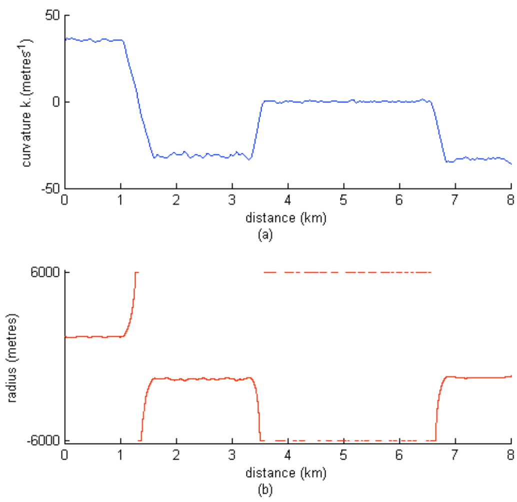


Figure 3

4.1.1 Curves

The next part of the segmentation selects sections which have a near constant curvature value. These sections are called curves, while the remaining sections of track are categorised as transition curves. The procedure for selecting curves is as follows.

1. Smooth the calculated radius signal based on a 50 metre moving average. Figure 4(a) shows in red the radius signal for the section of track from 1.5 to 3.5 km shown in Figure 3. The dashed black line represents the smoothed radius signal.

2. Numerically calculate the gradient of the smoothed radius signal, to be called the delta radius. This is achieved by calculating the differences between adjacent elements of the smoothed radius. Figure 4(b) shows the calculated delta radius in red. This is then smoothed based on a moving average of 25 metres, shown by the black dashed line.

3. Curves are defined as sections with consecutive delta radius values between -0.75 and +0.75. The dashed red lines in Figure 4(b) are placed at 0.75; the section of track whose delta radius lies between these values is categorised as a curve.

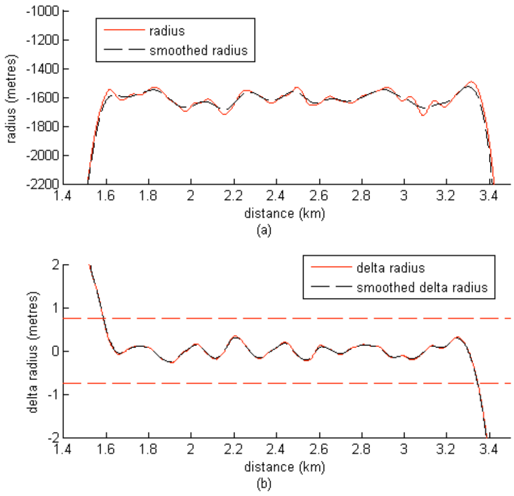


Figure 4

4. Remove any curved sections selected as above which are less than 100 metres in length.

5. Place the curves into one of the following categories based on their radius. If a curved section lies on the boundary of two categories and has radius values in both, it is placed in the category where its median radius value lies.

- radius < 0.3 km
- 0.3 ≤ radius < 0.7 km
- 0.7 ≤ radius < 1.0 km
- 1.0 ≤ radius < 1.5 km
- 1.5 ≤ radius < 3.0 km
- 3.0 ≤ radius < 6.0 km

4.1.2 Results of segmentation

Table 4 to Table 7 show the results of the segmentation described in the sections above. The total number of sections of each type is shown for each IM, along with the minimum, maximum, median and mean section lengths. The track category types are as follows.

(a) tangent (b) radius < 0.3 km (c) 0.3 ≤ radius < 0.7 km (d) 0.7 ≤ radius < 1.0 km (e) 1.0 ≤ radius < 1.5 km (f) 1.5 ≤ radius < 3.0 km (g) 3.0 ≤ radius < 6.0 km

Track type	Total number of sections	Min. section length (m)	Max. section length (m)	Median section length (m)	Mean section length (m)
(a)	2121	100.8	18614.8	627.4	1159.3
(b)	13	125	394.2	218.2	222.5
(c)	114	102.2	839.6	280.2	307.0
(d)	170	107.6	1797.6	423.5	507.1
(e)	540	101.4	1921.8	426.1	559.4
(f)	1231	101.8	2609.4	293.8	419.7
(g)	604	103	2370.8	189.1	272.4

Table 4: Lengths of each type of track for Network Rail

Track type	Total number of sections	Min. section length (m)	Max. section length (m)	Median section length (m)	Mean section length (m)
(a)	226	104.6	24569.1	923.28	2070.78
(b)	0				
(c)	8	139.8	881.76	419.44	479.68
(d)	13	138.4	915.04	318.88	385.25
(e)	11	232.96	912	593.92	603.21
(f)	13	128.96	1039.68	639.84	567.52
(g)	121	100.04	2767.68	368.48	644.64

Table 5: Lengths of each type of track for Deutsche Bahn

Track type	Total number of sections	Min. section length (m)	Max. section length (m)	Median section length (m)	Mean section length (m)
(a)	344	101.5	12519.3	333.62	708.18
(b)	35	101.75	927.25	175.75	248.87
(c)	127	100.75	665.75	210	257.48

(d)	44	105.75	1193.75	257	324.43
(e)	27	112.5	708	232.5	298.68
(f)	24	102.5	2492.5	544.25	720.69
(g)	33	110	2196.5	386	677.63

Table 6: Lengths of each type of track for ÖBB

Track type	**Total number of sections**	**Min. section length (m)**	**Max. section length (m)**	**Median section length (m)**	**Mean section length (m)**
(a)	189	101	4409	387.25	573.41
(b)	0				
(c)	67	104.75	789.75	238	273.06
(d)	25	115.75	798.25	217.5	271.6
(e)	17	120	520.75	193.75	221.95
(f)	46	101.5	866	213.12	281.42
(g)	0				

Table 7: Lengths of each type of track for Banverket

5. Data processing

The following sections describe the ways in which the TRV data has been processed. The lateral alignment data corresponding to the shortest wavelength filter provided by each IM is first smoothed using a moving average filter in order to aid the calculation of the wavelengths via the distance between maximum points, and via the number of zero crossings. The alignment data is also transformed to the spatial frequency domain via the Fourier transform.

5.1.1 Smoothed alignment data

The alignment data is smoothed based on a ±2 metres moving average in order to aid the automatic identification of the wavelengths of the alignment signal. This is discussed in the section below. Unsmoothed and smoothed alignment data for 0.5 km of track for each IM is shown in Figure 5. The data is for the average alignment of left and right rails filtered by the shortest wavelength filter provided by the IM. Note that throughout this section, the IMs and track sections are not be identified. Rather, a description of the line type and traffic conditions will be given for the track sections that are analysed in detail in sections 5.4 – 5.7.

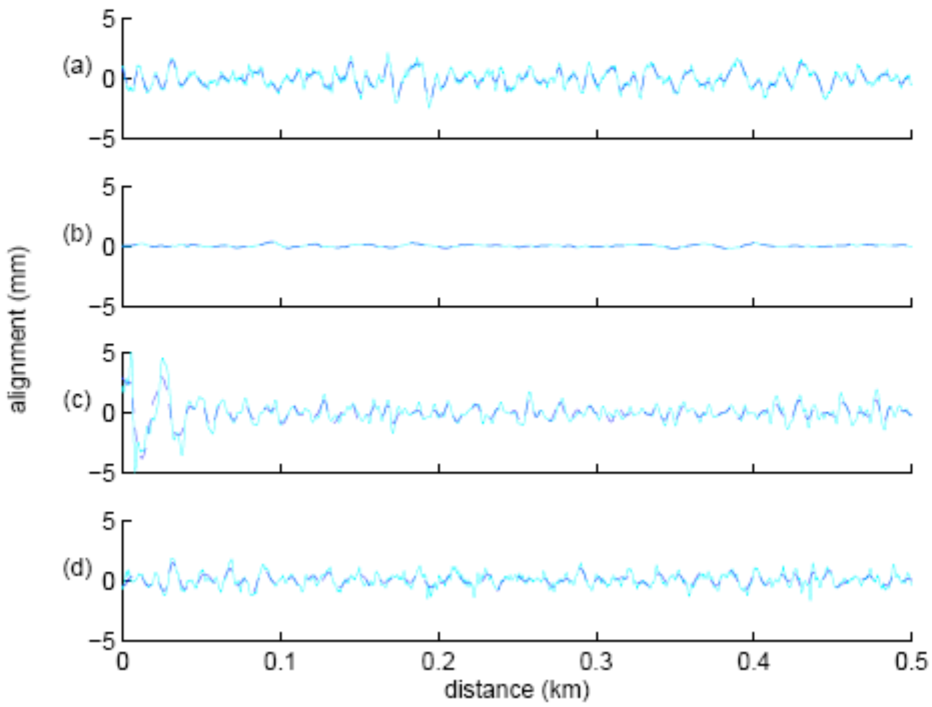


Figure 5: Examples of alignment data (cyan solid line) and smoothed alignment data based on a 2 metre moving average (blue dashed line) for 0.5 km of track for each of the infrastructure managers (a) IM A (b) IM B (c) IM C (d) IM D

5.1.2 Calculation of wavelength via maximum points

The minima and the maxima of the smoothed alignment signal may be numerically calculated by locating turning points within the signal. Figure 6 shows the alignment and smoothed alignment for 0.2 km of Network Rail track. The minima and maxima of the smoothed alignment are marked with red and black crosses, respectively. The wavelength is then measured as the distance between maxima (or alternatively, between minima).

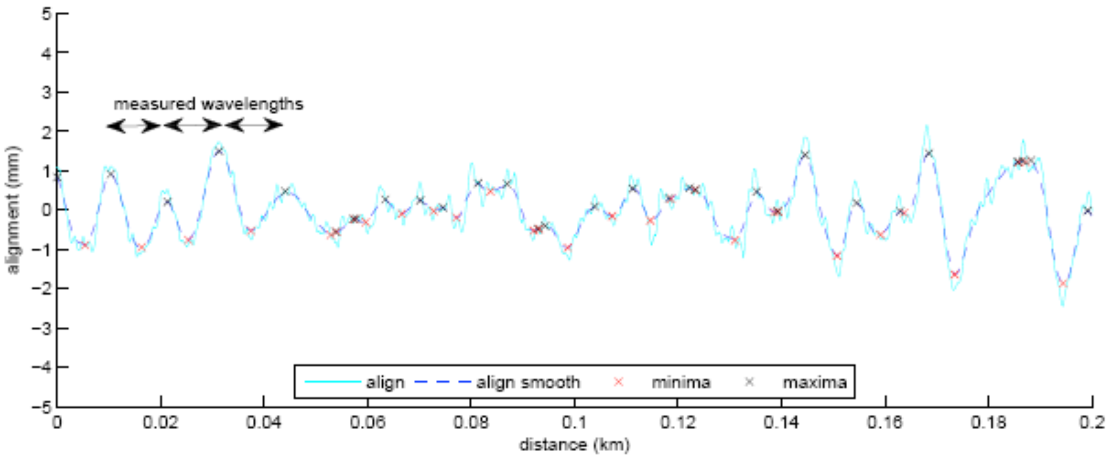


Figure 6

5.1.3 Measurement of wavelength via zero crossings

The number of zero crossings is calculated simply by counting the number of times that the alignment value of zero is crossed within a given section. An estimation of the average wavelength within that section can then be calculated by dividing the number of zero crossings by the section length.

5.1.4 Fourier analysis

Identification of the spatial frequency components (1/wavelength) can be aided by performing the Fourier transform. By converting to the spatial frequency domain, the discrete Fourier transform of the alignment signal can be found using the fast Fourier transform (FFT). The single sided amplitude frequency spectrum may then be plotted. It shows spatial frequencies up to half the sampling frequency, where the sampling frequency is the number of points at which recordings are taken by the TRV per metre. The transformed alignment data will be plotted against the wavelength (1/frequency) since it is this rather that the spatial frequency which is of interest here. Wavelengths which occur more commonly than others within the data will appear as amplitude peaks within the data.

5.2 Analysis of tangent sections

Figure 7 shows the alignment signal transformed to the spatial frequency domain for all of the tangent sections provided by each of the IMs. Of these, the IM B graph (b) shows significantly lower amplitudes than for the other IMs. This corresponds to the alignment data which generally shows significantly lower amplitude measurements than for the other IMs. IM B's Fourier transformed data, along with that of IM A (a) and IM C (c) graphs do not show any significant amplitude peaks, especially compared to the graph of IM D (d) which has a clear peak at 10 metres, along with several smaller peaks.

These graphs give an overview of the spatial frequency spectrum for all the tangent sections provided by each IM. Since a principal aim of this exercise is to analyse any sections of consistent wavelengths in the Klingel wavelength range (approximately 5-20 metres) amongst the data provided, it is necessary to study shorter sections of track. If any sections of consistent wavelength are present amongst the tangent sections of IM A – IM C's data, they may form a very small portion of the total track, and therefore do not show up as amplitude peaks in Figure 7(a) to (c). Analysis of shorter sections of track should allow the identification of sections with a consistent wavelength in the alignment data. The consistent wavelength observed at 10 metres in the spectrum of IM D may also be further investigated in this way. Identification of sections of interest (or the lack of any sections containing a consistent wavelength) must be performed before comparisons based on geometric properties of the track could be performed.

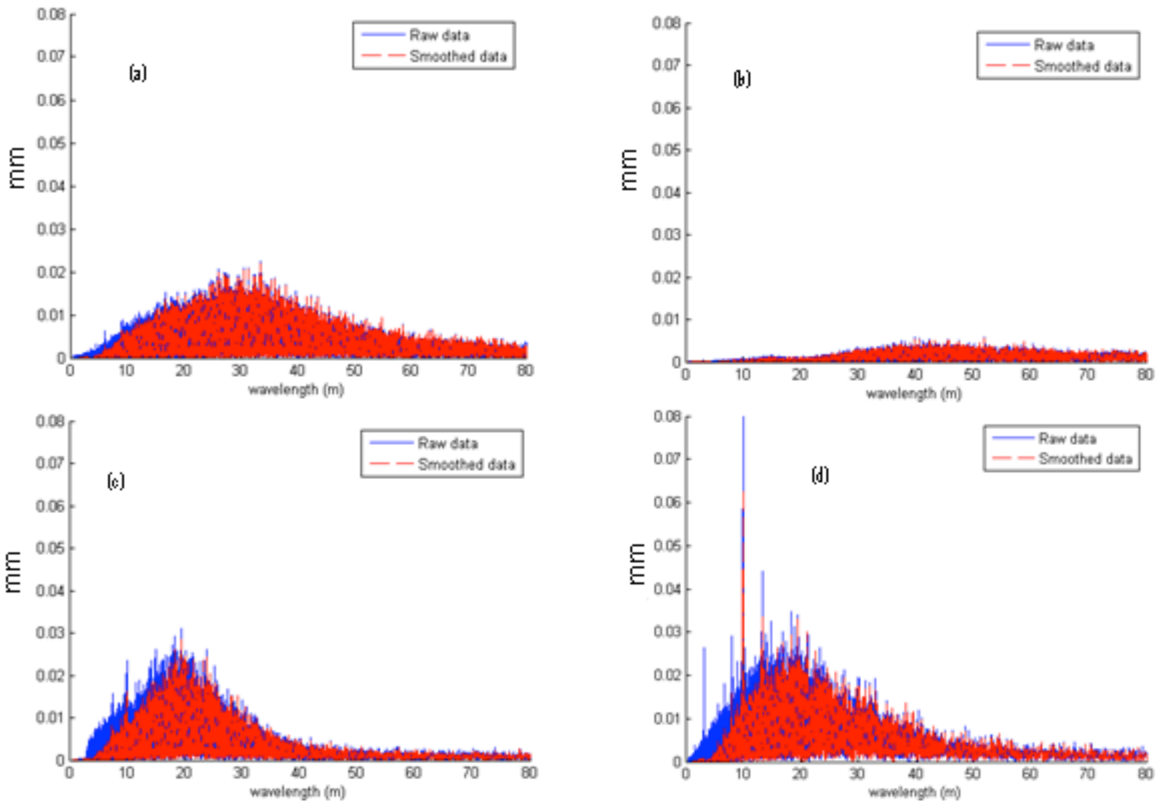


Figure 7: Fourier transform of alignment data for all tangent sections provided by (a) IM A, (b) IM B, (c) IM C, (d) IM D

5.3 Analysis of random alignment data

This section describes the generation of a random signal which mimics the amplitude measurement of the TRV. The random signal will then be filtered and smoothed in the same way as the TRV data has been. The aim of this is to analyse the effects of applying the Fourier transform to a totally random signal, and to a random signal combined with a signal of a given wavelength (10 meters in this case). The signals containing both a random part and a part with a consistent wavelength should show an amplitude peak in the Fourier transformed signal. The significance of this will help decide the length of track sections that should be analysed to avoid missing any sections of track containing a section of consistent wavelength, even if it is a short section.

5.3.1 Random signal

At equally spaced distances (defined to be equal to the inter-measurement distance) a random value (may be positive or negative) is added to the previous random value. These values are interpreted as the alignment measurements in millimetres.

A random amplitude signal generated in this way, and its Fourier transform is shown in Figure 8. The inter-measurement distance here is 20 cm. There are 50001 points, equivalent to 10 km of alignment data. The random numbers generated have a normal distribution with mean 0 and standard deviation

1. The signal has been passed through a bandpass filter so that wavelengths of between 1 and 35 metres are allowed to pass. It has then been smoothed using the same ±2 metre moving average filter that is applied to the TRV data.

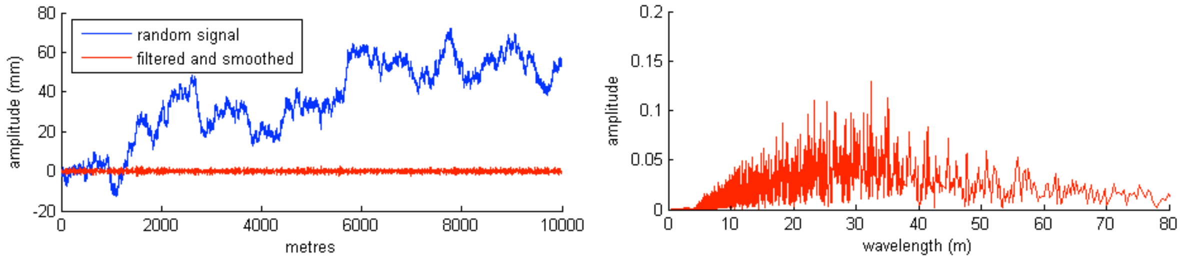


Figure 8: Random signal

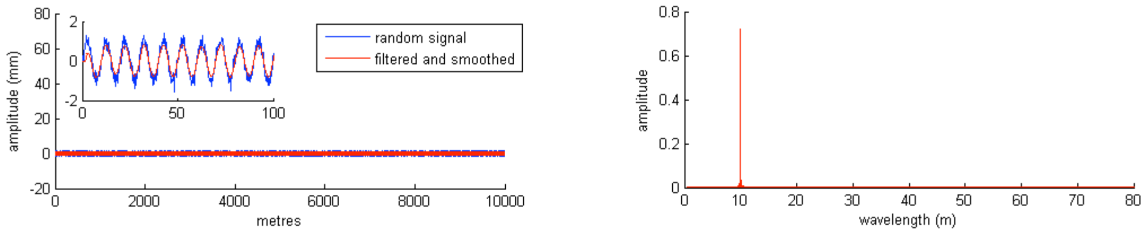


Figure 9: 100% consistent 10m wavelength signal (with added noise)

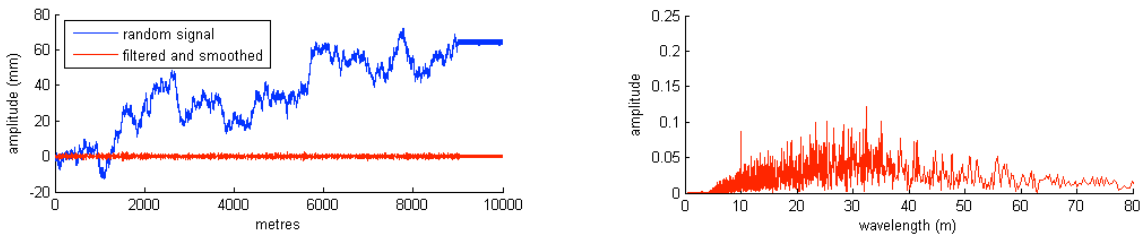


Figure 10: 90% random signal + 10% consistent 10m wavelength signal

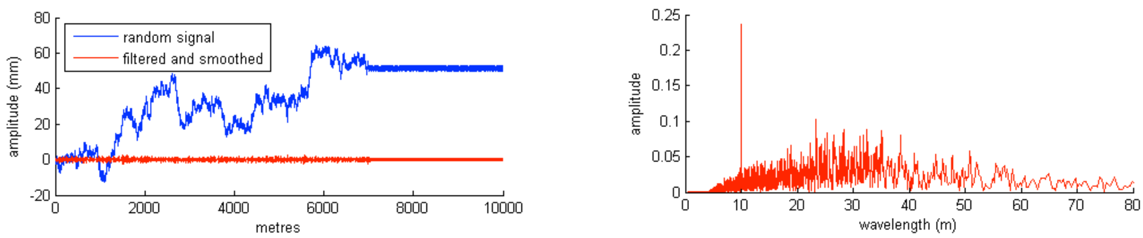


Figure 11: 70% random signal + 30% consistent 10m wavelength signal

It is clear from Figure 9, which shows the random signal that no amplitude peaks are observed in the Fourier spectrum, whereas in Figure 10 a very clear amplitude peak occurs as a wavelength of 10 metres, as expected since this figure corresponds to a sine wave with wavelength of 10 metres. By considering the significance of the peaks at 10 metres in Figure 10 and Figure 11, which contain 10% and 30% respectively of signal with 10 metre wavelength, while the rest of the signal is noise, it is suggested that analysing 2km sections of data should allow the identification of sections of consistent wavelength contained in the 2km section.

5.4 Analysis of Track Section a

By analysing the Fourier transforms of 2km long sections of IM A track, it was possible to identify several sections which show a small peak in amplitude in the Klingel wavelength range. One of these with the most significant amplitude peaks are analysed below.

The section of track shown in Figure 12 is taken from a secondary line carrying both passenger and freight traffic up to 5 million tonnes per annum. A clear amplitude peak can be seen at 9.1 metres. Figure 13 shows this section of track broken down into 200 metre segments and Table 8 shows the wavelengths that were measured for each section via the zero crossing method and via measurements between maximum points (see section 5 for a description of these).

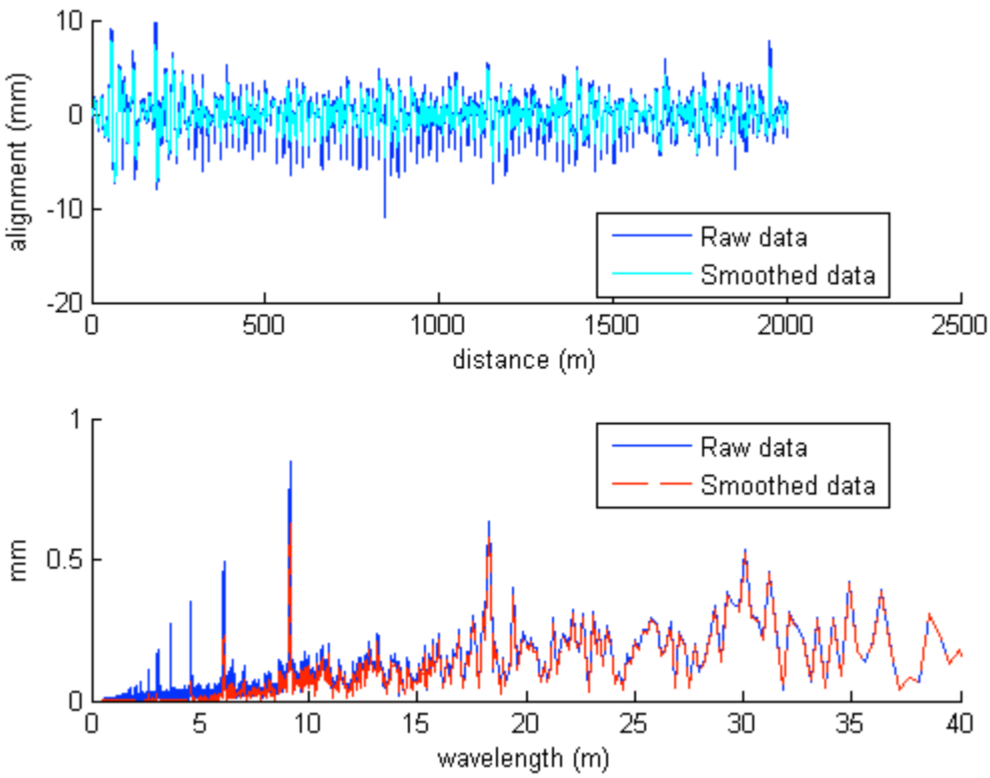
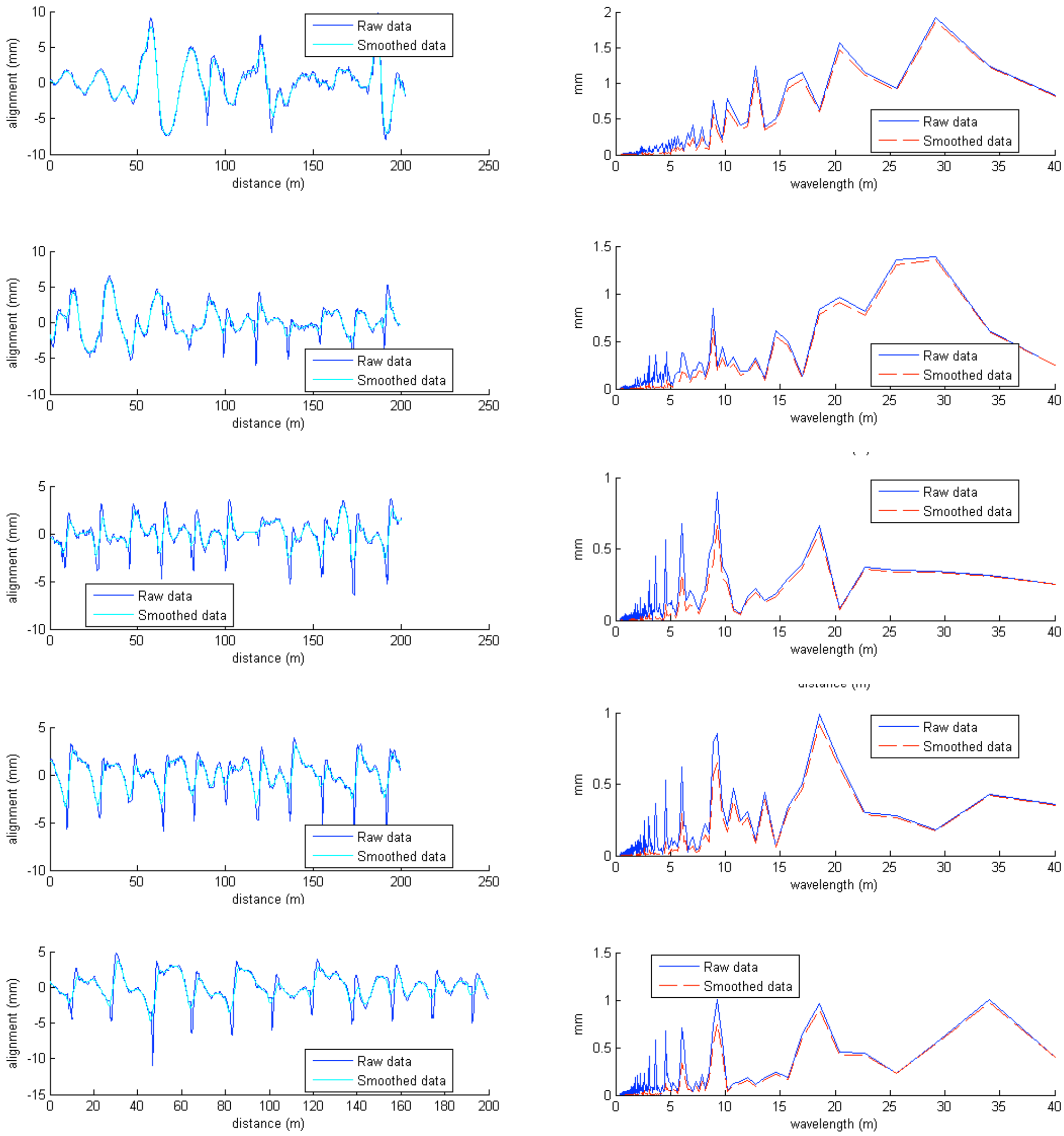


Figure 12

Section	**Wavelength via dist. between maxima (m)**	**Wavelength via zero crossing (m)**
1	8.27	13.63
2	9.58	11.34
3	7.15	12.44
4	8.86	11.98

5	8.65	12.98
6	9.73	13.50
7	8.41	14.49
8	8.04	12.94
9	8.25	11.49
10	7.87	11.15

Table 8



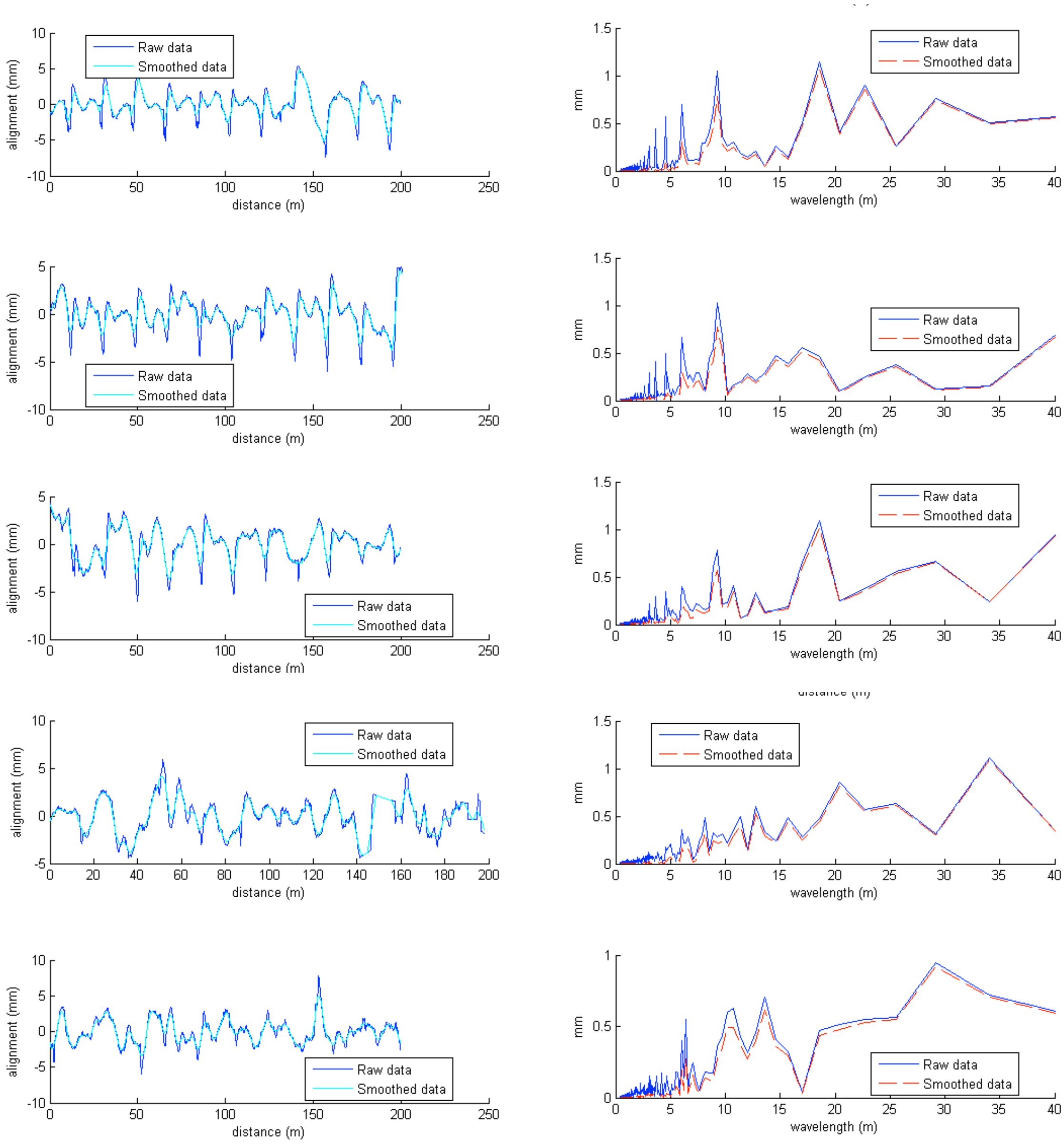
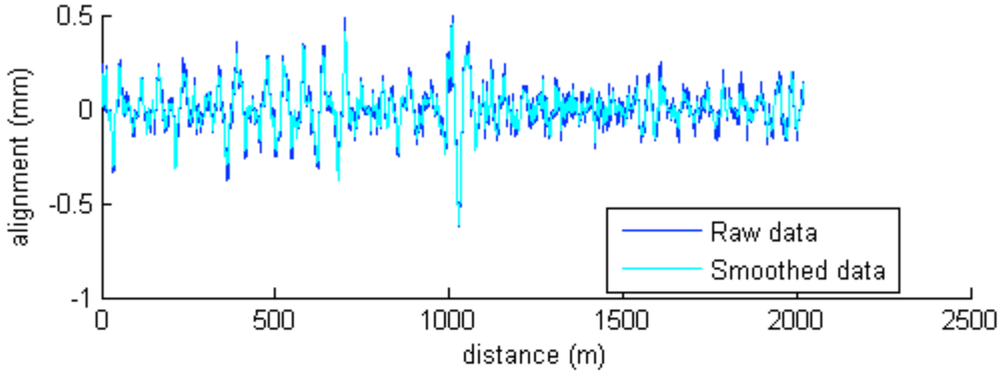


Figure 13

5.5 Analysis of Track Section b

The alignment data of IM B has significantly lower amplitude throughout all of the TRV files when compared to the alignment data of the other IMs. For example, Figure 14 shows a 2km section of track, whose amplitude varies between approximately + 0.5 mm and – 0.5 mm. This is typical of all of IM B's alignment data. It was not possible to select a 2km section of track from this IM which showed an amplitude peak in the spatial frequency spectrum, suggesting that no sections of consistent wavelength occurred in the lateral alignment data in the TRV files provided by this IM. For completeness, however, a 2km section of track is shown below and is split into 200 metre sections as for the other IMs. This section comes from a high speed line (250 km/h standard speed) with mixed passenger and express freight traffic. Table 9 shows the results of measurements of the wavelengths using the zero crossing method and by measuring between maxima.



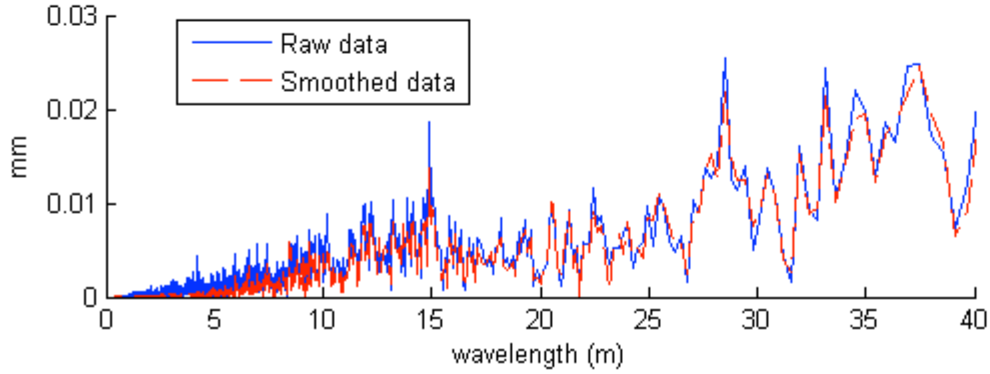
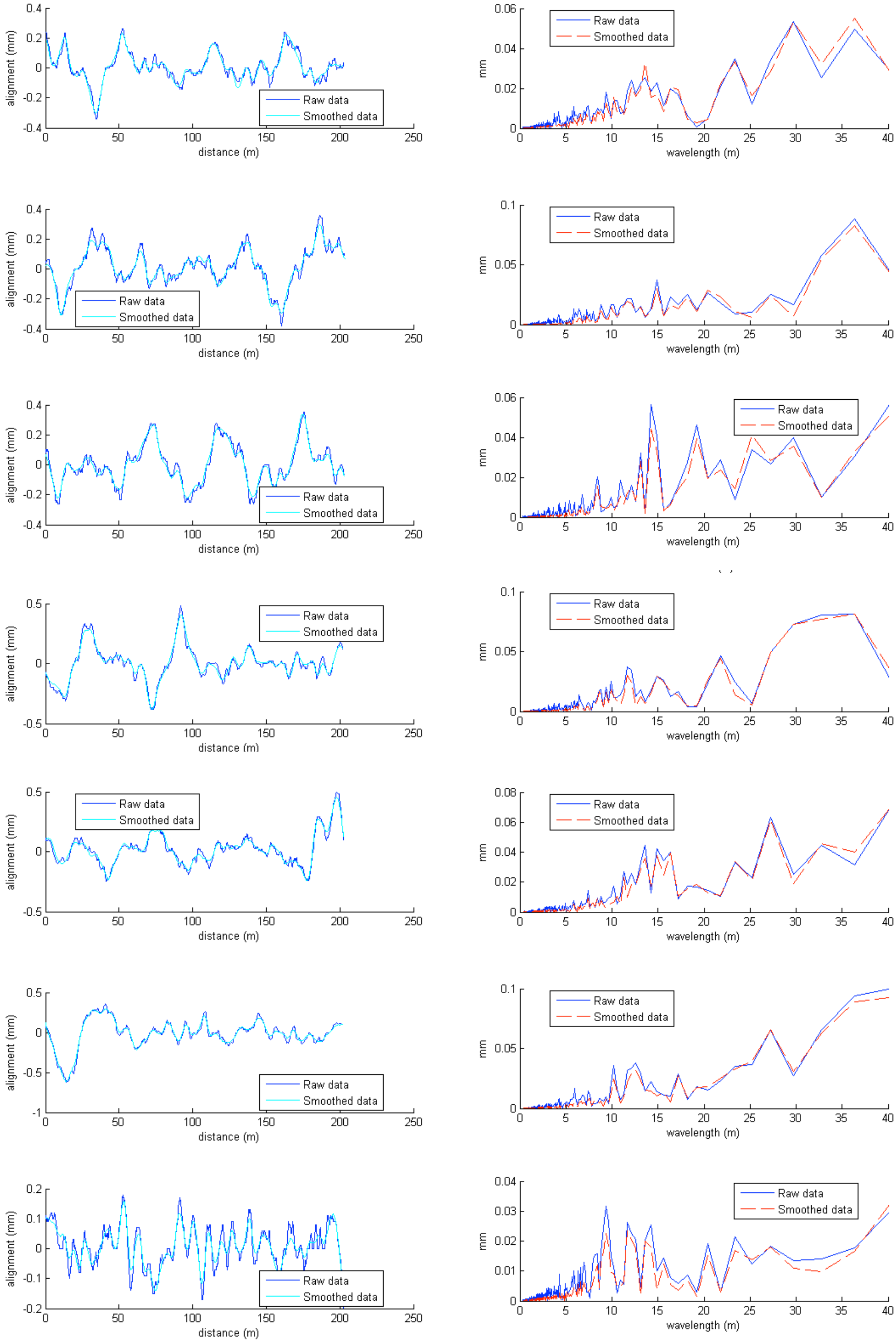


Figure 14

Section	**Wavelength via dist. between maxima (m)**	**Wavelength via zero crossing (m)**
1	8.27	8.11
2	8.23	7.89
3	11.69	5.90
4	7.92	5.41
5	8.18	7.41
6	9.96	4.93
7	7.75	8.89
8	8.22	13.31
9	5.76	13.30
10	6.76	8.47

Table 9


alignment (mm)
distance (m)
Raw data
Smoothed data
mm
wavelength (m)

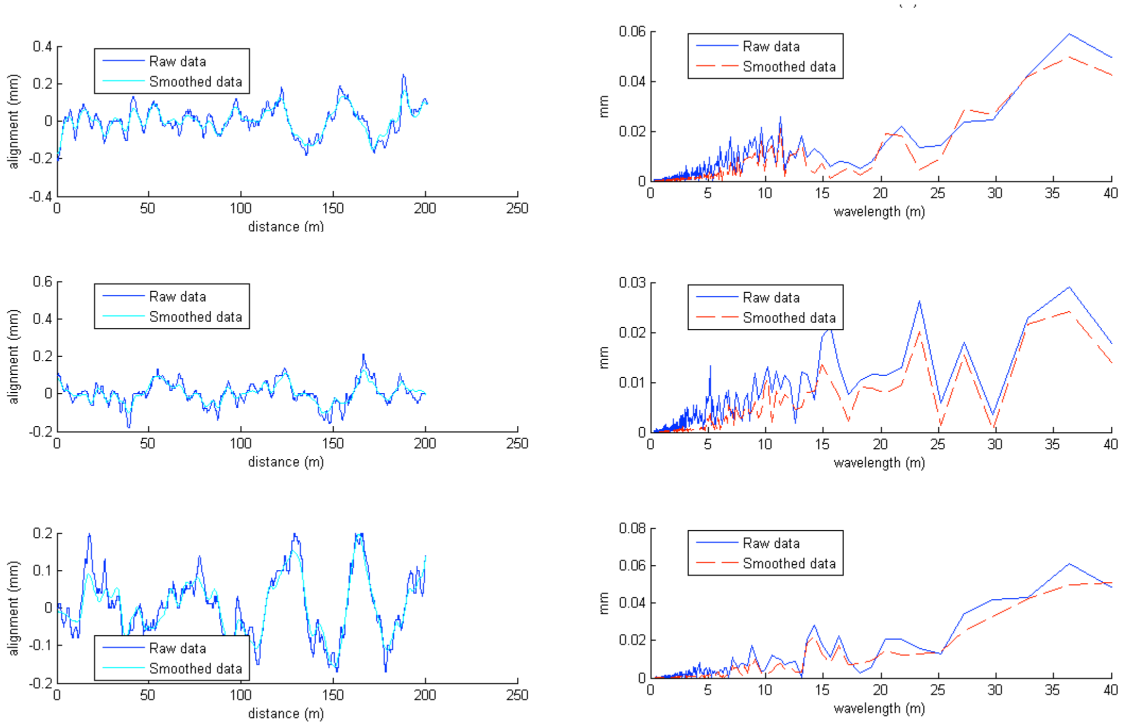


Figure 15

5.6 Analysis of Track Section c

For IM C's TRV data, it was possible to observe amplitude peaks at wavelengths in the Klingel range in a small number (approximately 5) of 2km sections. One of these is shown below in Figure 16. It occurs on a mixed traffic line with a top speed of 140 km/h. The amplitude peak occurs at a wavelength of 9.94 metres. Several of the 200 metre long sections in Figure 17 show evidence of the amplitude peak at 9.94 metres. This suggests that a consistent wavelength may have become embedded in the track at these locations. Table 10 shows the results of measuring the wavelengths within the 200 metre sections via the zero crossing and distance between maxima methods.

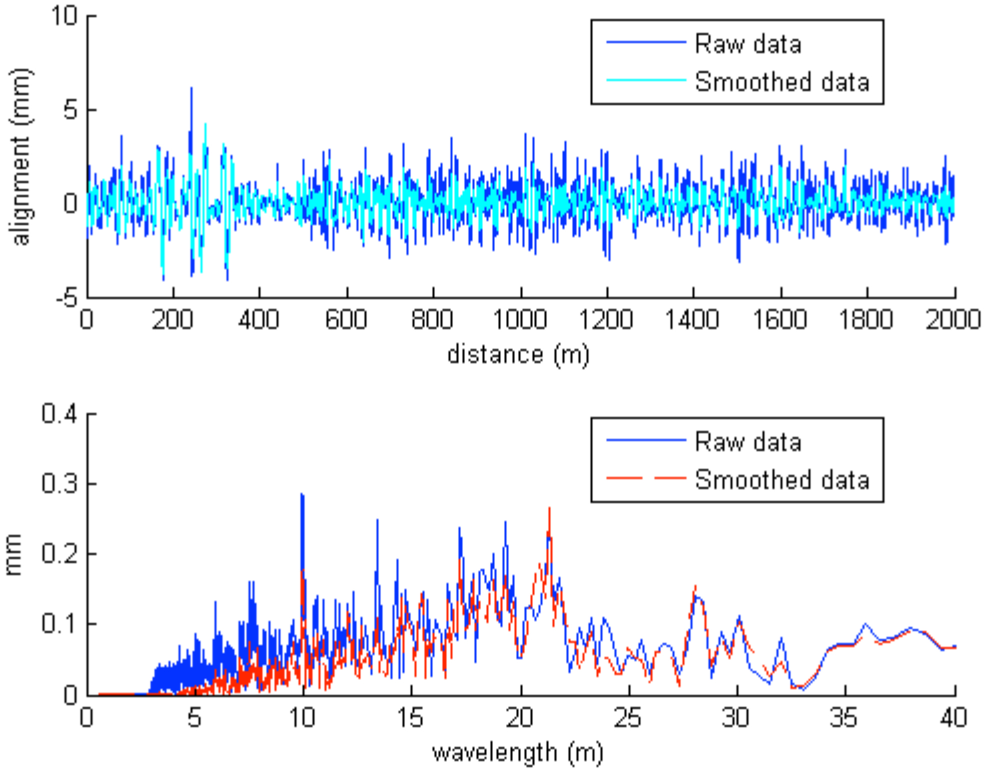
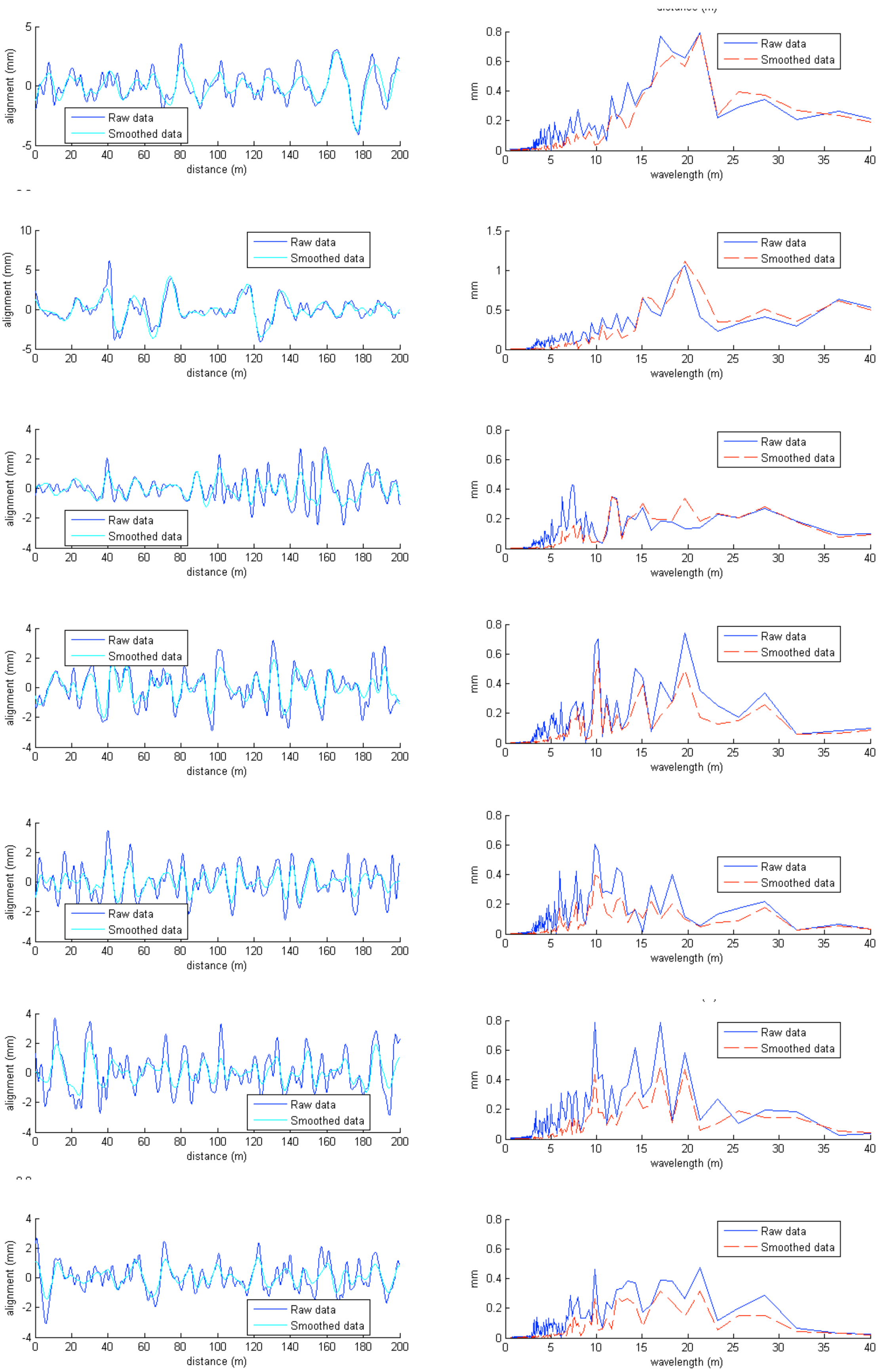


Figure 16

Section	Wavelength via zero crossing (m)	Wavelength via dist. between maxima (m)
1	12.43	12.5
2	12.60	11.5
3	9.56	14.0
4	8.68	12.5
5	7.85	13.0
6	9.51	12.0
7	11.0	10.5
8	9.92	9.25
9	8.69	13.0
10	8.33	13.25

Table 10


alignment (mm)
distance (m)
Raw data
Smoothed data
mm
wavelength (m)

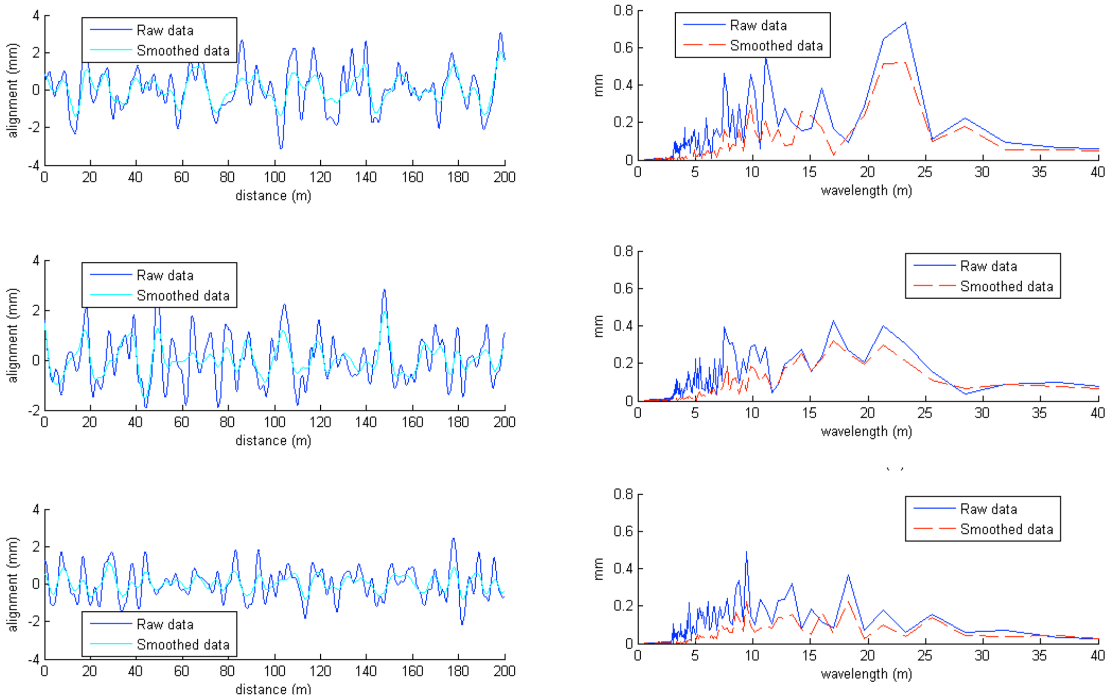


Figure 17

5.7 Analysis of Track Section d

The spatial frequency spectrum for the tangent sections of IM D in Figure 7(d) shows a significant amplitude peak at 10 meters, suggesting that a consistent wavelength of 10 metres may make up a significant portion of the alignment data provided by this IM.

TRV data was provided for 4 sections of track by IM D. When the complete set of alignment data for each was transformed to the spatial frequency domain using the Fourier transform, the alignment data for a heavy haul line showed the most significant amplitude peak at 10 metres. This line is used mainly by freight traffic with an axle load of 30 tonnes, and very limited additional traffic. The spatial frequency components of the 37km of alignment data from this line are shown in Figure 18 and Fourier transforms of 2km sections are shown in the annexe. From these it is possible to see a significant amplitude peak at 10 metres, although this peak significantly decreases in amplitude in the later sections.

Figure 19 shows a 2km section of the heavy haul line. This is shown in further detail below, by splitting it into sections of 200 metres. In the graphs of Figure 20, the alignment is shown beside the Fourier transform of each section.

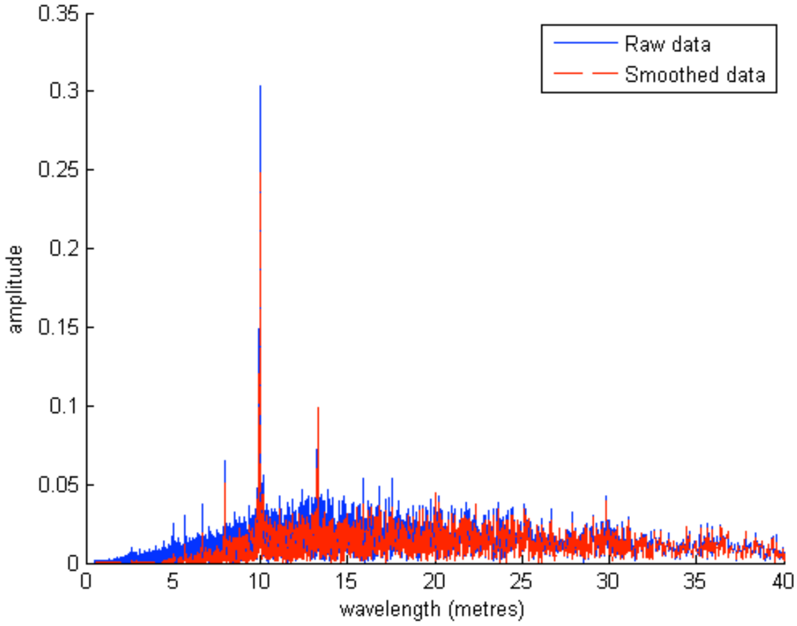


Figure 18

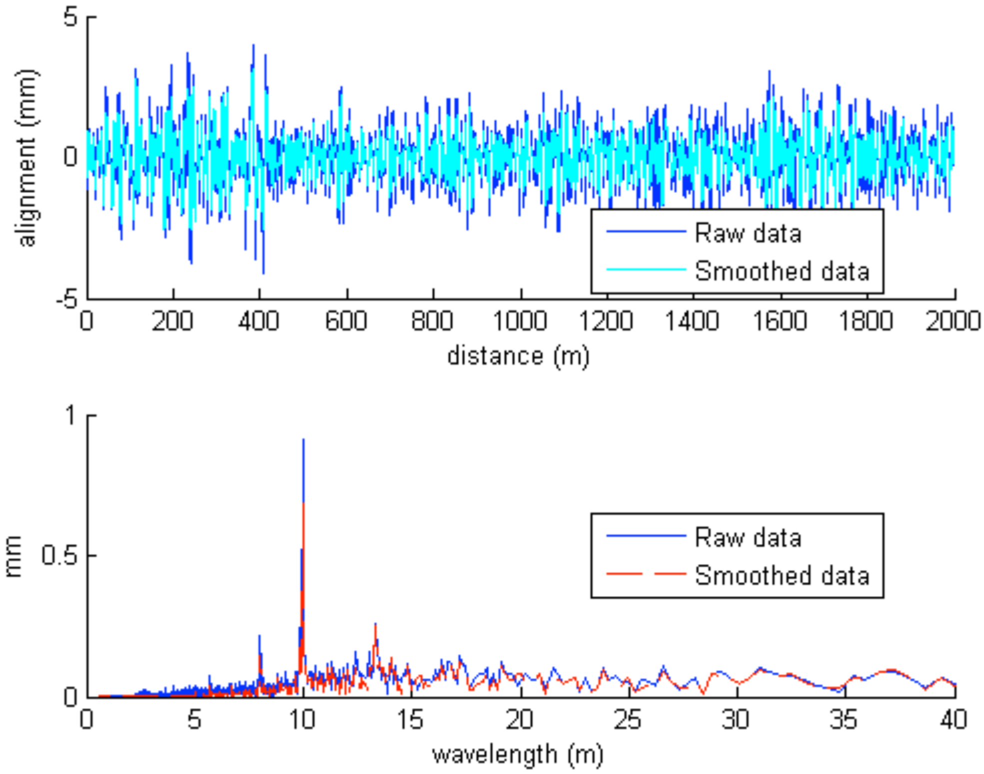
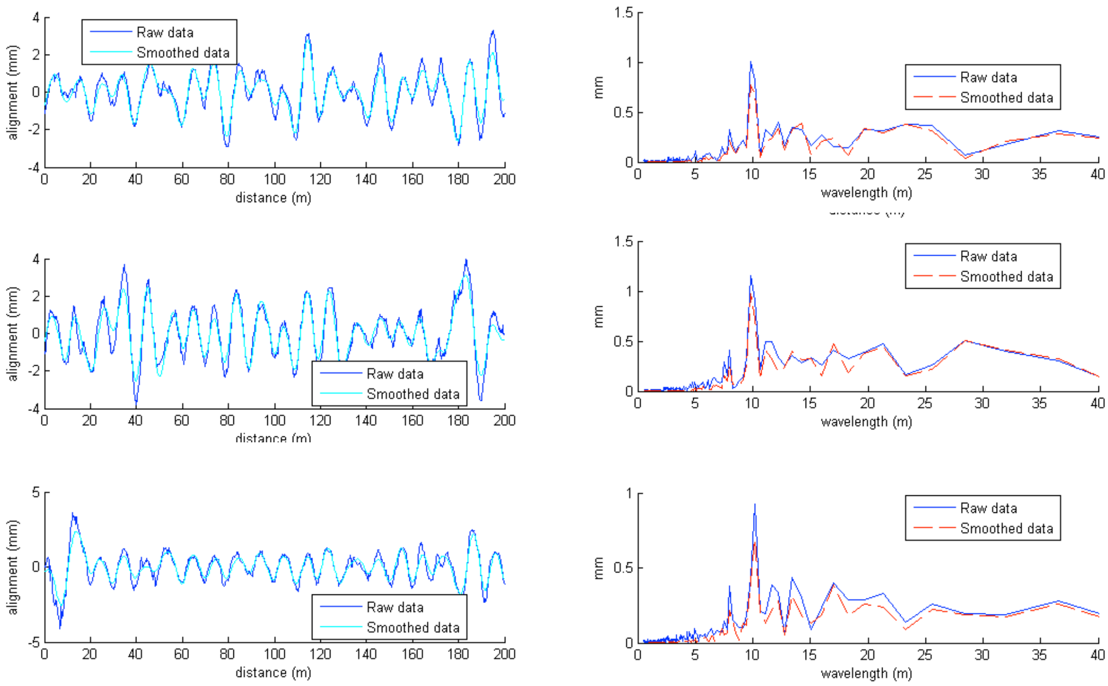


Figure 19

Section	**Wavelength via zero crossing (m)**	**Wavelength via dist. between maxima (m)**
1	9.35	9.31
2	8.50	9.3
3	9.00	9.63
4	9.50	7.93
5	9.00	9.36
6	10.0	10.10
7	10.0	8.33
8	9.50	9.26
9	9.50	9.38
10	9.25	9.84

Table 11

Table 11 shows the wavelengths measured via zero crossings and via measurements between maximum points. These results suggest that a consistent 10 metre wavelength in large parts of the lateral alignment of track section d. However, the fact that the consistent wavelength occurs at precisely 10 metres suggests that this reading could be caused by the filtering process applied to the raw TRV data since it is an exact multiple of the inter-measurement distance. The lateral alignment data from IM D's track is significantly different to any of the lateral alignment data from the other IMs in that a consistent wavelength is observed over large sections of tracks, whereas the sections showing a consistent wavelength in the alignment data of the other IMs are short and very limited in number.



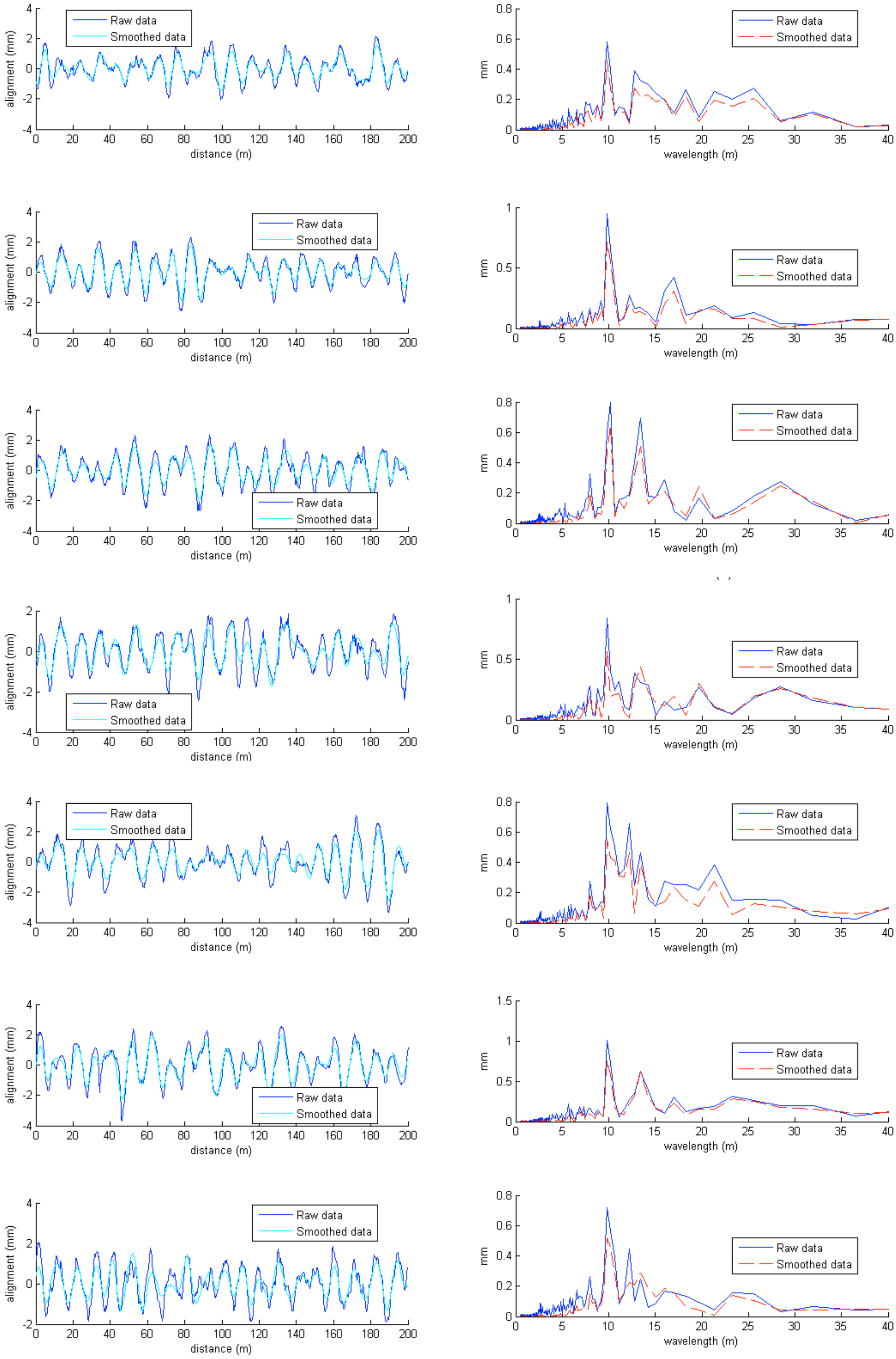

alignment (mm)
distance (m)
Raw data
Smoothed data
mm
wavelength (m)

Figure 20

6. Conclusions

This work has identified several sections of the order of a few hundred metres in length which show a consistent wavelength in the lateral alignment data of IM A and IM C. It was not possible, however, to identify any sections showing a consistent wavelength in IM B's TRV data using this method. The lateral alignment data of IM D showed sections of several kilometres in length with what appears to be a consistent wavelength of 10 metres, particularly on the heavy haul line analysed in section 5.7.

Since there are so few sections containing consistent wavelengths (except in the data from IM D), it is not possible to perform a meaningful comparison between track sections of similar geometric characteristics. However, it may prove worthwhile to study the identified sections showing consistent wavelength in greater depth, in particular to see whether any RCF patches similar to those previously observed on British track [1] are present.

6.1 Further work

More detailed investigations could take the primary yaw suspension stiffness (PYS) of the vehicles on the route under investigation. This is because the PYS changes vehicle rolling behaviour compared to the single free axle which is used in the Klingel model.

Patches of RCF separated by consistent distances within the expected Klingel wavelength range have been observed on British track [1]. It would be useful to closely study the TRV data corresponding to these sections and compare the analysis of this data to the track RCF observations.

7. Bibliography

[1] Recent findings in the understanding of vehicle/track interaction on track damage and rolling contact fatigue (RCF) M. C. Burstow, M. A. Dembosky, S. Gurule and C. Urban

[2] D1.2.5 Methodology for Generic Track Segmentation Approach

[3] Track Segmentation – IM Report Network Rail - S. Thornton, Corus

[4] Track Segmentation – IM Report ÖBB S. Thornton, Corus

[5] Track Segmentation – IM Report PRORAIL S. Thornton, Corus

[6] Track Segmentation – IM Report SNCF S. Thornton, Corus

[7] Track Segmentation – IM Report Deutsche Bahn S. Thornton, Corus

[8] General data for 3 different tracks in Sweden Arne Nissen, Banverket

8. Annexes

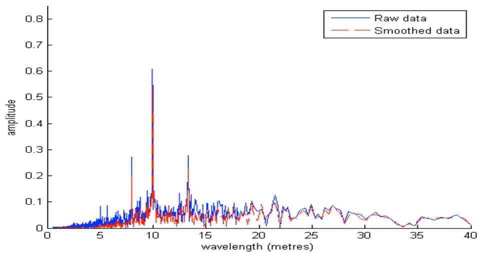
Description of data files provided by Network Rail

Description	**Length (km)**
Weaver Junction to Liverpool	27.6
Crewe South Yard to Weaver Junction	40.75
Golbourne Junction via Preston and Lancaster to Crewe	343
Warrington South to Golbourne Junction via Newton-le-Willows	273
Liverpool Lime Street to Crewe South	57.7
Bridge Street Junction to Paisley Gilmour Street to Gourouck via Stonybrae	31
Bridge Street Junction to Paisley Gilmour Street to Gourouck via Stonybrae	31
Stonybrae to Gourouck	30
Wembyss Bay Junction to Wembyss Bay	16
Bethnal Green Junction to Norwich	221
Continuation of above	
Earsdon to Bedlington to Benton (North) Junction to Earsdon	17.6
Continuation of above	
Bedlington South to Lynemouth	10.3
Continuation of above	
West Sleekburn Junction to North Blythe	5
London Victoria via Windmill Bridge and Earlswood to Brighton	96.8
Continuation of above	
London to Brighton – Stoats Nest to Earlswood	93.3
Continuation of above	
Glasgow to Crewe via Gretna	392
Crewe to Glasgow via Gretna	392
London Euston to Crewe to Hillmorton	298
Continuation of above	
Law Junction to Glasgow Central to Loch Green Junction to Ayr	93.8
Ayr to Glasgow Central	93.8
Glasgow to Crewe via Gretna	392
Crewe to Glasgow via Gretna	392

London Euston to Rugby Trent Valley Junction	133
Rugby Trent Valley Junction to Stafford Trent Valley No 1 Junction	80
London Kings Cross to Newcastle	429
Newcastle to English/Scottish Border	111
ECM1 1100 to ECM1 1200 to ECM1 3607	302
PMJ 1150 to PMJ 2150 to EMP 2100 to ECM1 2200	139
English/Scottish Border to Edinburgh Wavely	197
Doncaster to Manors	182

Frequency transforms of IM D heavy haul line divided into 2km sections (see section 5.7)

1



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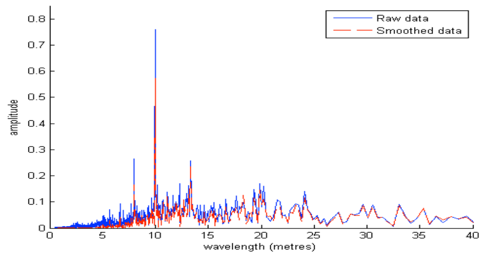

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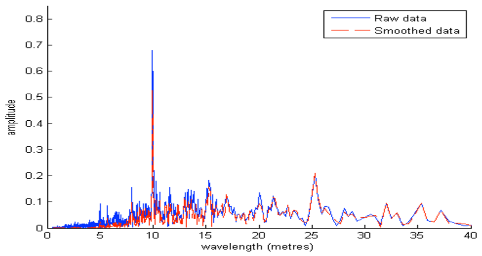

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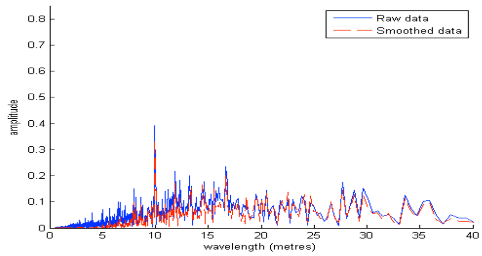

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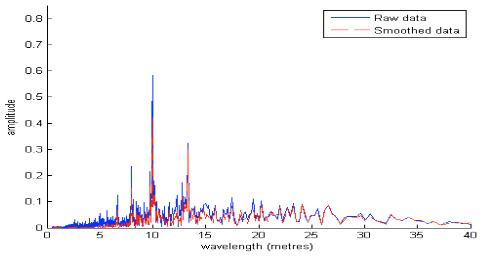

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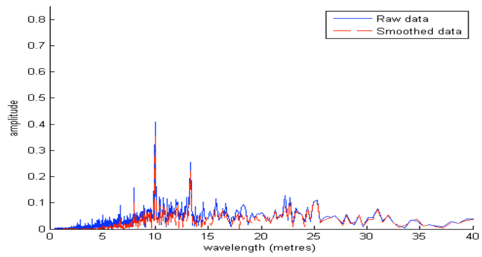

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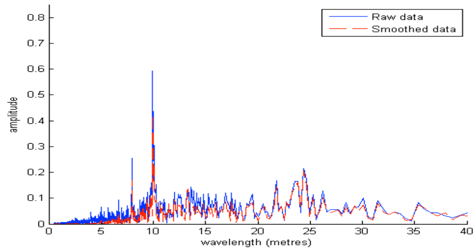

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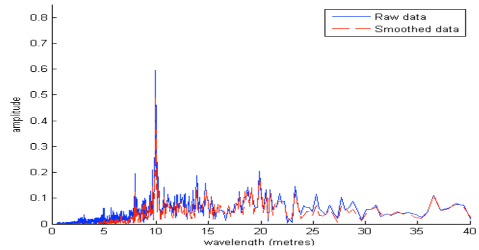

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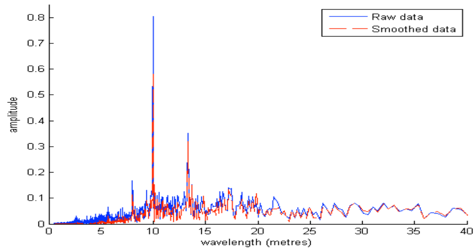

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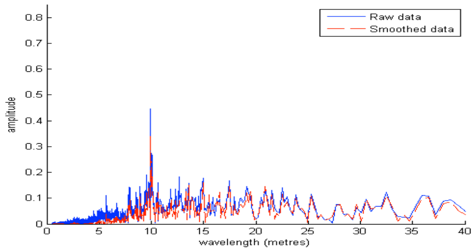

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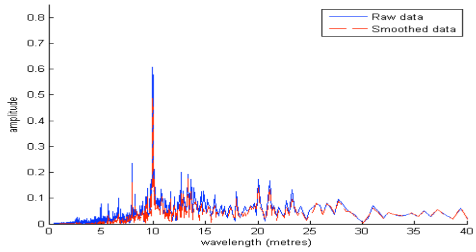

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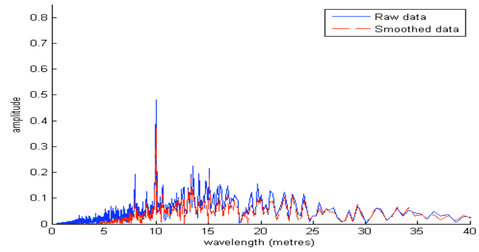

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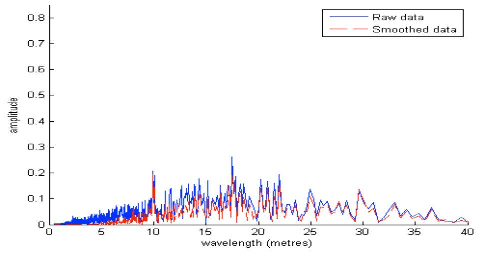

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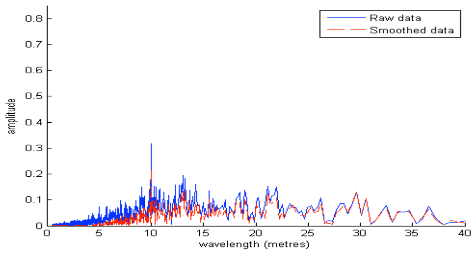

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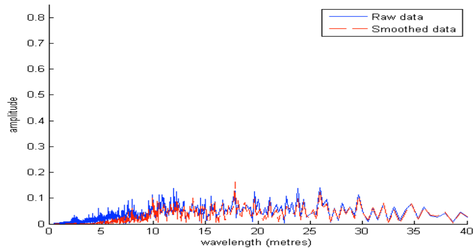

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