



# Barrier separated road type design

## Accelerated degradation

Terence McGarvey



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## Abstract

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To reduce the risk of vehicular head-on collisions, the Swedish Transport Administration (Trafikverket), has been transforming high traffic-volume conventional roads into barrier separated roads. This process has reduced the number of fatalities by around 80 percent.

However, evidence has shown that barrier separated roads degrade quicker than conventional road types.

The extent of the problem was quantified by comparing various sets of road surface characteristic data. Comparisons revealed that degradation levels increase by up to 60 percent in the single lane sections of 2+1 type barrier separated roads.

Vehicle position surveys were carried out and subsequent data analysis confirmed that confinement of vehicle lateral wander is a main cause of the problem. The analysis indicated that in the single lane section of a 2+1 type barrier separated road, vehicle lateral wander reduced by 24 percent for light vehicles and 19 percent for commercial traffic. These figures increased to 44 percent and 39 percent for a 1+1 type barrier separated road.

Accelerated degradation can be attributed to poor cross-sectional design. The amount of vehicular lateral wander is restricted and results in surface wear and loading being concentrated in narrow tracks along the road section.

Design improvements are possible but will obviously require higher initial investment expenditure.

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## Referat

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För att minska risken för frontalkrockar har Trafikverket omvandlat högt trafikerade traditionellt utformade vägar till mötesfria vägar. Denna omvandlingsprocess har minskat antalet dödsolyckor med ungefär 80 procent.

Dock har det visat sig att mötesfria vägar bryts ner snabbare än traditionellt utformade vägar.

Omfattningen av problemet har kvantifierats genom att jämföra olika datauppsättningar om vägytors karakteristiska egenskaper. Dessa jämförelser visade att spårdjupsutvecklingen ökade upp till 60 procent på de enfiliga sträckorna av mötesfria vägar som 2+1-vägar.

Undersökningar av fordonsposition utfördes också och en efterföljande analys bekräftade att inskränkning i fordonens sidolägesvariation utgjorde en väsentlig del av problemet. Analysen indikerade att på enfiliga sträckor av 2+1-vägar minskade sidoförflyttning med 24 procent bland lätta motorfordon och 19 procent bland tunga. Dessa siffror ökade till 44 procent respektive 39 procent för 1+1-vägar.

Accelererad nedbrytning uppstår på grund av dålig tvärsnittsdesign. Sidoförflyttning av fordon begränsas, vilket resulterar i slitage och att belastning koncentreras till smala spår längs med vägsträckan.

Designförbättringar är möjliga, men kräver större initiala investeringsinsatser.

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## Foreword

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This project has been funded in total by the Swedish Transport Administration.

Investigations, data analysis, photographing and report writing have been carried out by Terence McGarvey (VTI).

Thanks, are given to Håkan Wilhelmsson (VTI) and Sven-Åke Lindén (formerly of VTI) who carried out the vehicle position surveys, and to Thomas Lundberg (VTI) who provided support regarding road surface survey data.

Final thanks are extended to Nils-Gunnar Göransson (VTI) and Carl-Gösta Enocksson (Swedish Transport Administration) for support and advice given throughout the project duration.

Linköping, June 2017

*Terence McGarvey*  
*Project leader*

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## Process for quality review

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Internal peer review was performed on 11 May 2016 by Anna Arvidsson. Terence McGarvey has made alterations to the final manuscript of the report. The research director Anita Ihs has examined and approved the report for publication on 21 March 2017. The conclusions and recommendations expressed are the author's and do not necessarily reflect VTI's opinion as an authority.

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## Process för kvalitetsgranskning

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Intern peer review har genomförts 11 maj 2016 av Anna Arvidsson. Terence McGarvey har genomfört justeringar av slutligt rapportmanus. Forskningschef Anita Ihs har därefter granskat och godkänt publikationen för publicering 21 mars 2017. De slutsatser och rekommendationer som uttrycks är författarens egna och speglar inte nödvändigtvis myndigheten VTI:s uppfattning.



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## Summary

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### **Barrier separated road design (2+1) – Accelerated degradation**

by Terence McGarvey (VTI)

Barrier separated roads enable near-motorway safety levels to be achieved at a much lower cost than with actual conversions to motorway or dual carriageway standards. Transforming a high traffic volume road into a barrier separated road type reduces the number of fatalities by around 80 percent. A large percentage of the high traffic volume road network in Sweden has already been transformed into 2+1 roads.

However, evidence has shown that barrier separated roads degrade quicker than conventional road designs.

The extent of the problem was quantified by comparing various sets of road surface characteristic data. These comparisons revealed increases in rut development of up to 60 percent in the single lane sections of 2+1 type barrier separated roads.

Vehicle position surveys were carried out and subsequent data analysis confirmed that vehicle confinement was a main cause of the problem. The analysis indicated that in the single lane section of a 2+1 type barrier separated road, vehicle lateral wander reduced by 24 percent for light vehicles and 19 percent for commercial traffic. These figures increased to 44 percent and 39 percent for a 1+1 type barrier separated road.

Factors such as lane width, verge width, total width between road edge and central barrier, and close proximity of the central barrier all had some influence on vehicle position and the amount of lateral wander.

In addition, the use of existing road surface materials may also contribute to the problem. Depending on traffic flow volumes, transforming a conventional road into a barrier separated road may result in increased specification standards. Use of an inferior existing surface could result in a 30 percent increase in surface wear.

Accelerated degradation can be attributed to poor cross-sectional design. The amount of vehicular lateral wander is restricted and results in surface wear and loading being concentrated in narrow tracks along the road section.

Design improvements are possible but will obviously require higher initial investment expenditure.



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## Sammanfattning

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### Mötesfria vägar – Accelererad nedbrytning

av Terence McGarvey (VTI)

Mötesfria vägar gör att säkerhetsnivåer liknande de på motorvägar kan åstadkommas till en mycket lägre kostnad än vid en faktisk ombyggnation till motorväg eller vägbana med dubbla körfält. En omvandling av en högtrafikerad väg till mötesfri väg minskar antalet dödsolyckor med cirka 80 procent. En stor andel högtrafikerade vägar i Sverige har redan omvandlats till 2+1-vägar.

Dock har det visat sig att mötesfria vägar bryts ner snabbare än traditionellt utformade vägar.

Omfattningen av problemet har kvantifierats genom att jämföra olika datauppsättningar om vägytors karakteristiska egenskaper. Dessa jämförelser visade att spårdjupsutvecklingen ökade upp till 60 procent på de enfiliga sträckorna av mötesfria vägar som 2+1-vägar.

Undersökningar av fordonposition utfördes också och i den efterföljande analysen bekräftades att fordonbegränsningar utgjorde en väsentlig del av problemet. Analysen indikerade att på enfiliga sträckor av 2+1-vägar minskade sidoförflyttning med 24 procent bland lätta motorfordon och 19 procent bland tunga. Dessa siffror ökade till 44 procent respektive 39 procent för 1+1-vägar.

Faktorer som filbredd, kantbredd, total bredd mellan vägkanten och centrala barriären samt närhet till den centrala barriären hade alla en viss inverkan på fordonets position och sidoförflyttning.

En genomgång av tekniska krav visade att det kanske inte är lämpligt att använda ett existerande slitlager när man designar mötesfria vägar. Beroende på volymen av trafik kan det behövas ökade tekniska krav i omvandlingen från en traditionell väg till mötesfri väg. Användande av undermåliga existerande slitlager kan öka slitaget med 30 procent.

Accelererad nedbrytning beror främst på dålig tvärsnittsdesign. Om sidoförflyttning av fordon begränsas, koncentreras slitage och belastning till smala spår längs med vägen.

Förbättrad design, till exempel breddade mitt- och sidovägrenar, ökar sidoförflyttning av fordon och minskar nedbrytning. Sådana åtgärder kräver dock större initiala investeringsinsatser.



## 1. Introduction

When driving on a conventional wide two-lane road, the risk of a head on collision is high and many motorists have been killed or severely injured in this type of accident. To reduce the number of casualties, Trafikverket, the Swedish Transport Administration, has been constructing barrier separated roads since 1998. Transforming high traffic volume roads to this type has reduced the number of fatalities by around 80% (Carlsson, 2009).

A barrier separated road is a specific type of two or three-lane road and is often referred to as a 1+1 or 2+1 road type. Recommended standard designs are described in the publications *Krav och råd för vägars och gators utformning* (Trafikverket, 2015). Typical layouts consist of two lanes in one direction and one lane in the other. The layout alternates every few kilometres and lanes are separated by a central barrier or wire fence. In certain circumstances 1+1 sections are required to form part of the layout.

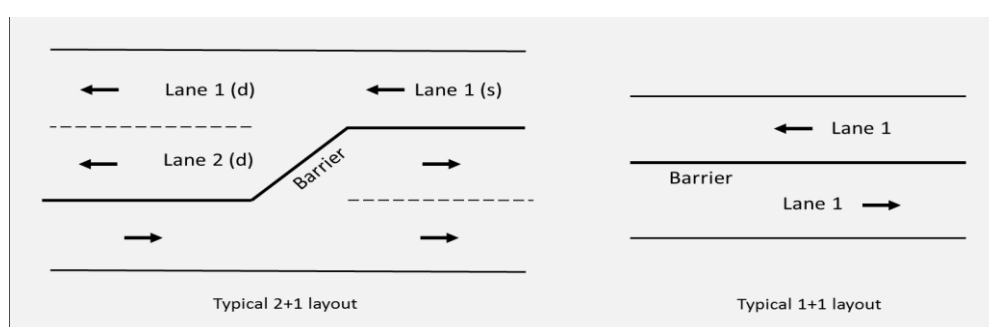


Figure 1. Barrier separated road type – typical layouts.

This type of design enables near-motorway safety levels to be reached at a much lower cost than actual conversions to motorway or dual carriageway standards. A large percentage of the high traffic volume road network in Sweden has already been transformed into barrier separated roads.

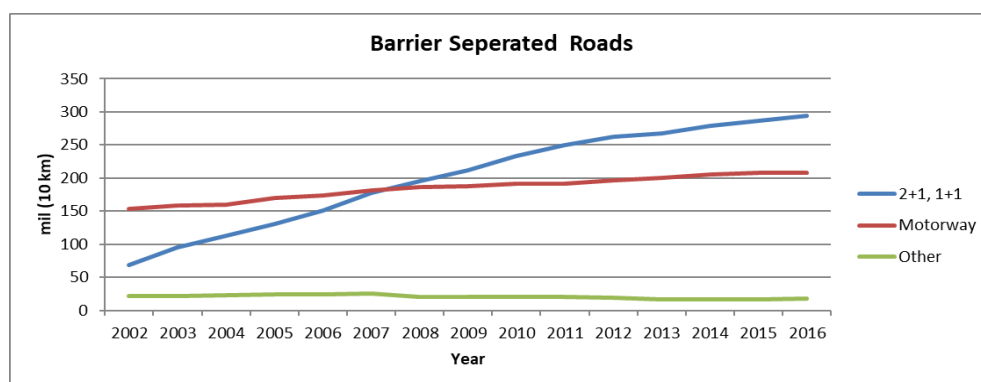


Figure 2. Barrier separated roads in Sweden (Trafikverket, 2017).

The above figure, which details the lengths of barrier separated road types in Sweden between 2002 and 2016, shows the increased investment in barrier separated road construction. Currently there are around 3000 km of 2+1 and 1+1 barrier separated roads and this is expected to rise to around 4 000 km after completion of planned construction projects. The road safety and construction cost benefits of barrier separated road type design are clear, however, evidence has shown that this type of road construction is prone to quicker degradation than with traditional designs (Carlsson, 2009 och Vadeby, 2016).

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## 2. Aim

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The aim in this project was to investigate why barrier separated roads, in particular 2+1 and 1+1 road types, were degrading at a faster rate than conventional designs.

The idea was to first quantify the problem and then determine likely causes. Once these causes were identified and understood, solutions to the problem could then be suggested.



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### 3. Method

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The first stage of the project was to confirm the occurrence of accelerated degradation. This was achieved by comparing rates of surface wear and deformation. Rut depth is one of many parameters measured annually on most of the Swedish bituminous road network. Data was used to determine initial and secondary rut development levels in the single and double lane sections found in barrier separated road types. Comparisons between the single and double sections and with conventional road types were then carried out.

The next stage involved identifying and investigating many possible causes of the problem. Causes investigated included the suitability of existing road surfaces, changes in vehicle speeds, and the confinement of vehicle lateral wander.

Vehicle position surveys were carried out on several Swedish road types and these provided useful data on vehicle position and lateral wander, traffic volume, vehicle speed, and vehicle classification. This data was used to show how vehicle behaviour varied in the different lane types.

Design, specifications, and construction practices were also considered. The aim was to try and increase the amount of vehicle lateral wander and reduce the amount of traffic over longitudinal vertical construction joints. This involved comparing vehicle position data with cross sectional designs.

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## 4. Accelerated Degradation

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### 4.1. General

Transformation strategies and methods vary depending on available budgets and technical knowledge. Existing road construction, road geometry, ground conditions and environment can also vary significantly. Variations to recommended design standards are also common. This means that every project is likely to be unique in some way.

### 4.2. Evidence

Evidence has shown that this type of road construction is prone to quicker degradation than with traditional designs.

One way accelerated degradation can be demonstrated is by comparing rutting or track development rates (mm per year) before and after transformation to barrier separated road type.

Analysis of road condition survey data from the Mälardalen region in Sweden (Håkan Jansson, 2011) showed that a significant increase in rut/track development occurred after a road section was transformed into a barrier separated road type. Rut development rates for barrier separated road types, with Annual Average Daily Flow (AADF) values between 2 000 and 8 000, typically ranged between 1.1 mm and 1.9 mm per year. This can be compared to the before transformation rates which ranged between 0.4 mm and 0.6 mm per year.

Additional statistical data (Carl-Gösta Enocksson, 2011) also indicated higher rut development rates for barrier separated road types. Analysis of this data, from all Swedish regions, showed that barrier separated road rut development rates ranged between 1.1 mm and 2.2 mm per year. Rut development rates for conventional road types ranged between 0.6 mm and 1.1 mm per year. The smallest rut development rate difference between the two road types was found to be in the Skåne region of Sweden.

Data also showed that barrier separated roads had the highest yearly rut development rates when plotted against three different traffic volume (AADF) groups; 1 000–3 999, 4 000–7 999 and over 8 000.

### 4.3. Example Studies

To try and understand where in the road the accelerated degradation was occurring, two barrier separated road sections were selected for study.

#### Location 1

The E4, between the Tönnebro and Söderhamn intersections, was reconstructed as a barrier separated road and opened to traffic in 2004.

The 25 km long project consists of fifteen 2+1 sections and three 1+1 sections. Section lengths vary between 800 and 2 000 m.

The maximum speed limit is 110 km/h.

Annual average daily flow (AADF) between 2006 and 2010 (Appendix 1):

- Northbound 3450
- Southbound 3650

Traffic consisted of approximately 80% light vehicles and 20% heavy vehicles.

Traffic growth between 2006 and 2010 was around 10%.

The surfacing course is an SMA (ABS) 11.

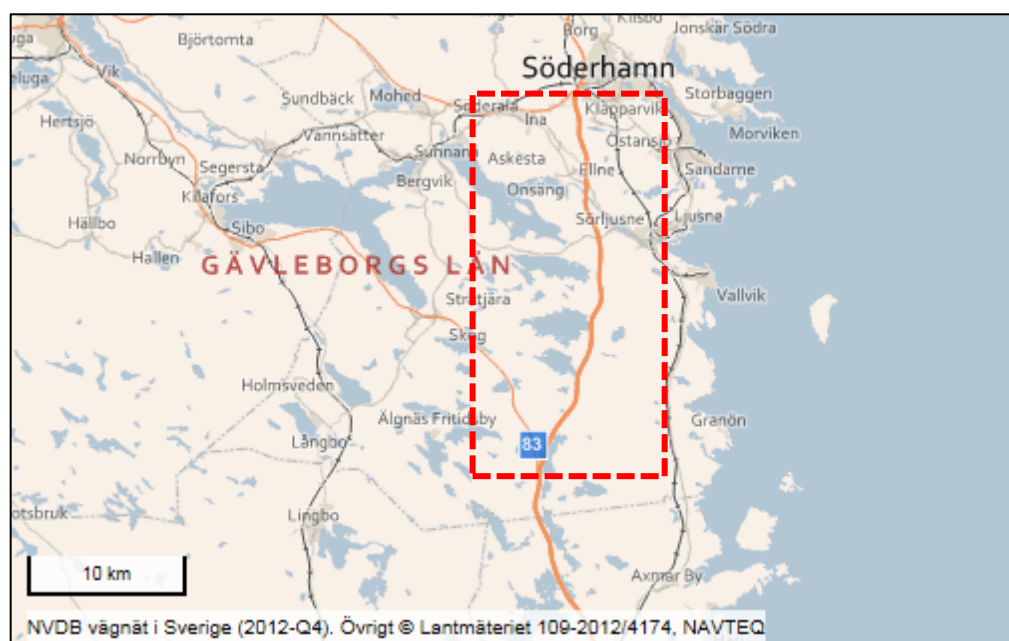


Figure 3. Example study location 1.

## Location 2

The E12, between Norrfors and Brattby, was reconstructed as a barrier separated road and opened to traffic in 2004.

The 9 km long project consists of four 2+1 sections and one 1+1 section. Section lengths vary between 750 m and 2 300 m.

The maximum speed limit is 90 km/h.

Average traffic volume between 2006 and 2010 (Appendix 2):

- North-west bound 3150
- South-east bound 3200

Traffic consisted of 90% light vehicles and 10% heavy vehicles.

Traffic growth between 2006 and 2010 was around 10%.

The surfacing course is an SA (MJOG) 16.

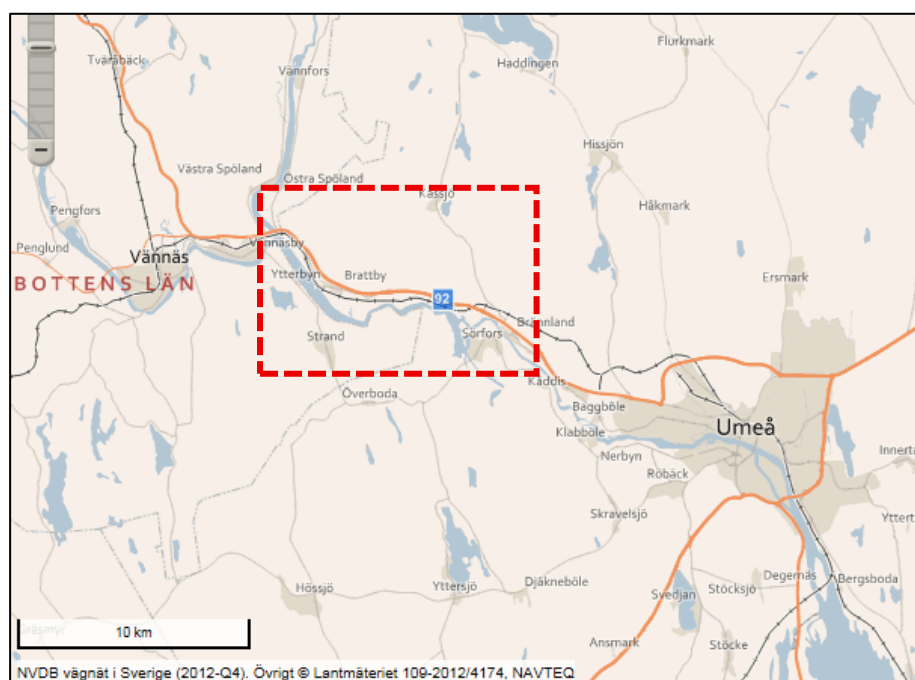


Figure 4. Example study location 2.

## Rut development comparisons

Due to the considerable number of variables that can influence pavement degradation, it is very difficult to accurately compare pavement performance. To increase the accuracy of the comparisons, each example was divided up into single lane, double lane and transition sections.

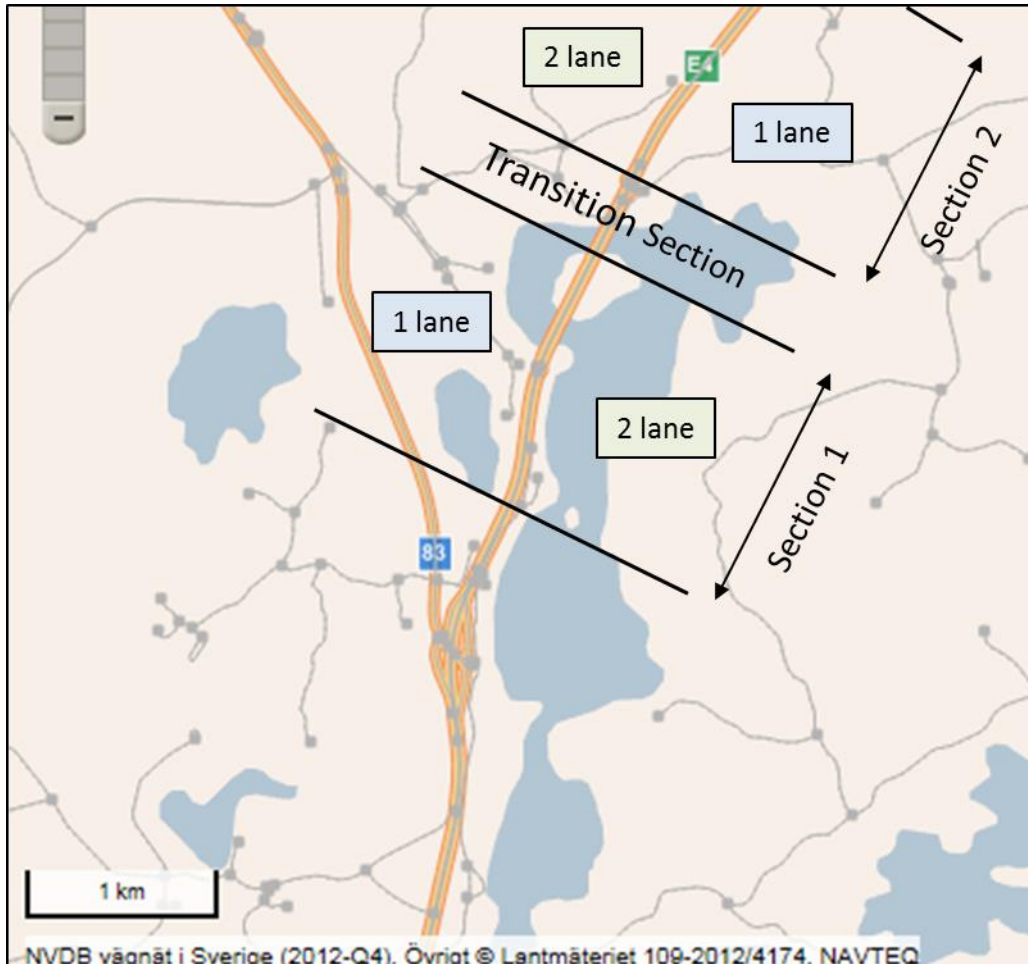


Figure 5. Map showing the E4 and the distribution of single lane, double lane, and transition sections.

Road surface condition data was used to calculate rut development rates on each section. Transition sections, between single and double lane sections, were ignored due to variations in lengths and lane widths.

In both cases some type of reconstruction work has been carried out:

- Location 1, E4 – after September 2010
- Location 2, E12 – before August 2009

This meant that useful data was limited to the following years:

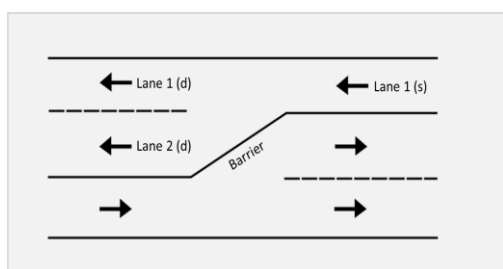
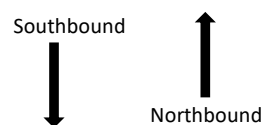
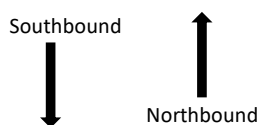
- Location 1, E4 – 2006, 2007, 2008, 2009 and 2010
- Location 2, E12 – 2009, 2010 and 2011

## Location 1, E4 – Rut Development

Using the available data (average maximum rut depth over a 20 m length) it was possible to calculate secondary phase rut development rates (mm per year) between 2006 and 2010. Also detailed in Table 1 are the 2006 rut depths. These depths, measured after approximately two years after construction, give an idea of the initial phase rut development.

Table 1. Rut depths (mm) 2006, and rut development (mm/year) 2006 to 2010.

Section Ref	Rut Depth (mm) 2006 (approx 2 years after opening)		Rut Development mm per year (2006 - 2010)	
	Lane 1 (d)	Lane 1 (s)	Lane 1 (d)	Lane 1 (s)
15	10.2	8.3	1.7	1.4
	-	-	-	-
14	10.4	12.1	1.1	1.8
	-	-	-	-
13	10.8	8.4	1.7	1.1
	-	-	-	-
12	6.9	10.8	0.9	1.7
	-	-	-	-
11	10.0	-	1.7	-
	-	-	-	-
10	10.3	8.4	1.0	1.7
	-	-	-	-
9	6.8	7.4	1.5	0.9
	-	-	-	-
8	7.7	7.2	0.9	1.5
	-	-	-	-
7	7.2	9.2	1.2	0.9
	-	-	-	-
6	7.8	8.8	1.0	1.4
	-	-	-	-
5	6.7	8.2	1.9	0.7
	-	-	-	-
4	7.8	7.7	1.1	1.4
	-	-	-	-
3	6.5	8.2	1.3	1.0
	-	-	-	-
2	9.9	7.5	1.0	1.6
	-	-	-	-
1	8.4	5.6	1.6	1.2



Lane 1 (d)	Double Lane Section
-	Transition section
Lane 1 (s)	Single Lane Section

Southbound results can be summarised as follows:

- Average rut development rate in the single lane sections, Lane 1(s), was 1.6 mm per year (Range between 1.2 mm and 1.9 mm)
- Average rut development rate in the double lane sections Lane 1(d) was 1.0 mm per year (Range between 0.9 mm and 1.1 mm)
- Initial rut development after approximately 2 years was high, especially between section references 10 and 15

Northbound results can be summarised as follows:

- Average rut development rate in the single lane sections, Lane 1(s), was 1.6 mm per year (Range between 1.8 mm and 1.4 mm)
- Average rut development rate in the double lane sections Lane 1(d) was 1.0 mm per year (Range between 0.7 mm and 1.4 mm)
- Initial rut development after approximately 2 years was high

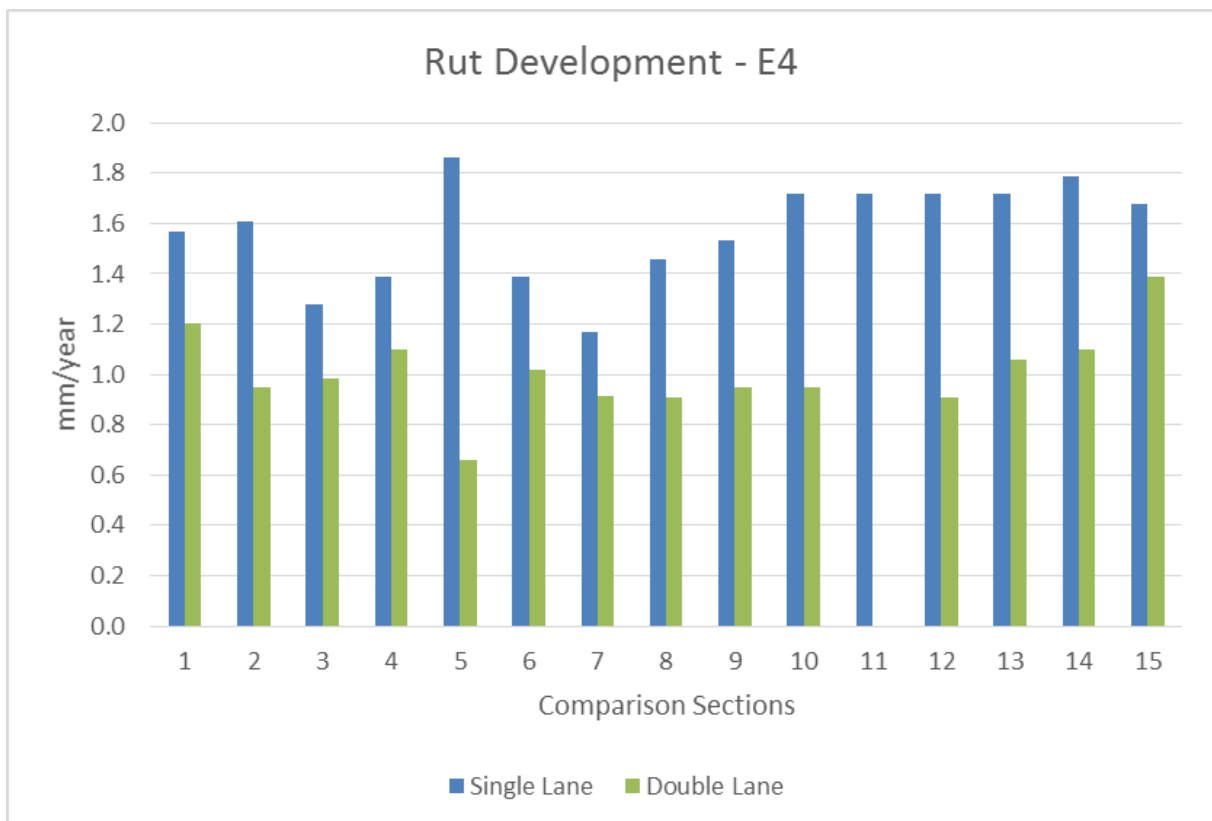


Figure 6. E4 rut development (mm per year).

## Location 2, E12 – Rut development

Using the available data (average maximum rut depth over a 20 m length) it was possible to calculate secondary phase rut development rates (mm per year) between 2009 and 2011. Also detailed in Table 2 are the 2009 rut depths. These depths, measured between one to two years after maintenance was carried out, give an idea of initial phase rut development.

Table 2. Rut depths (mm) 2009, and rut development (mm/year) 2009 to 2011.

Section Ref	Rut Depth (mm) 2009 (1 or 2 years after resurfacing)		Rut Development mm per year (2009 - 2011)	
	Lane 1 (d)	Lane 1 (s)	Lane 1 (d)	Lane 1 (s)
4	4.2	3.1	1.3	1.9
	-	-	-	-
3	3.3	5.0	1.7	1.3
	-	-	-	-
2	5.8	3.6	1.4	1.4
	-	-	-	-
1	2.8	4.8	1.5	0.9

South-east

↓

↑

North-west

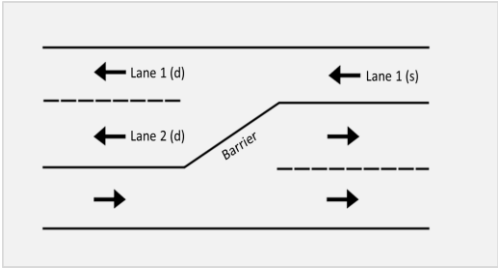
South-east

↓

↑

North-west



Lane 1 (d) Double Lane Section

- Transition section

Lane 1 (s) Single Lane Section

South-east bound results can be summarised as follows:

- Average rut development rate in the double lane sections, Lane 1(d), was 1.4 mm per year (Range between 1.3 mm and 1.4 mm)
- Average rut development rate in the single lane sections, Lane 1(s), was 1.6 mm per year (Range between 1.5 mm and 1.7 mm)

Northwest bound results can be summarised as follows:

- Average rut development rate in the double lane sections, Lane 1(d), was 1.1 mm per year (Range between 0.9 mm and 1.3 mm)
- Average rut development rate in the single lane sections Lane1(s) was 1.7 mm per year (Range between 1.4 mm and 1.9 mm)





Figure 7. E12 rut development (mm per year).

#### 4.4. Conclusion

The considerable number of variables that can influence pavement degradation make it very difficult to divide a road into sections and accurately compare pavement performance. However, in these two examples, rut development rates were up to 60% higher in the single lane sections.

An unknown number of vehicles will have been driven in lane 2 of the double lane section. Most of these vehicles are likely to be light vehicles and this will account for a small percentage of the difference between the rut development rates.

If the effects from factors such as traffic volume, construction specifications, and workmanship standards are considered to be consistent through each section, it can be suggested that differences in degradation rates are a result of variations in the road layout.

These differences, which must be influencing how vehicles are driven in the available space, are investigated further in the following chapters.

## 5. Possible causes of accelerated degradation

When a road section is transformed into a barrier separated road, factors such as traffic volume, studded tyre usage, environmental conditions, and winter maintenance methods are unlikely to change.

However, differences will occur in the way that the road is designed, constructed and maintained. Significant differences will also be apparent in the way vehicles use the available road space.

The following figure shows how these differences could be related to accelerated degradation.

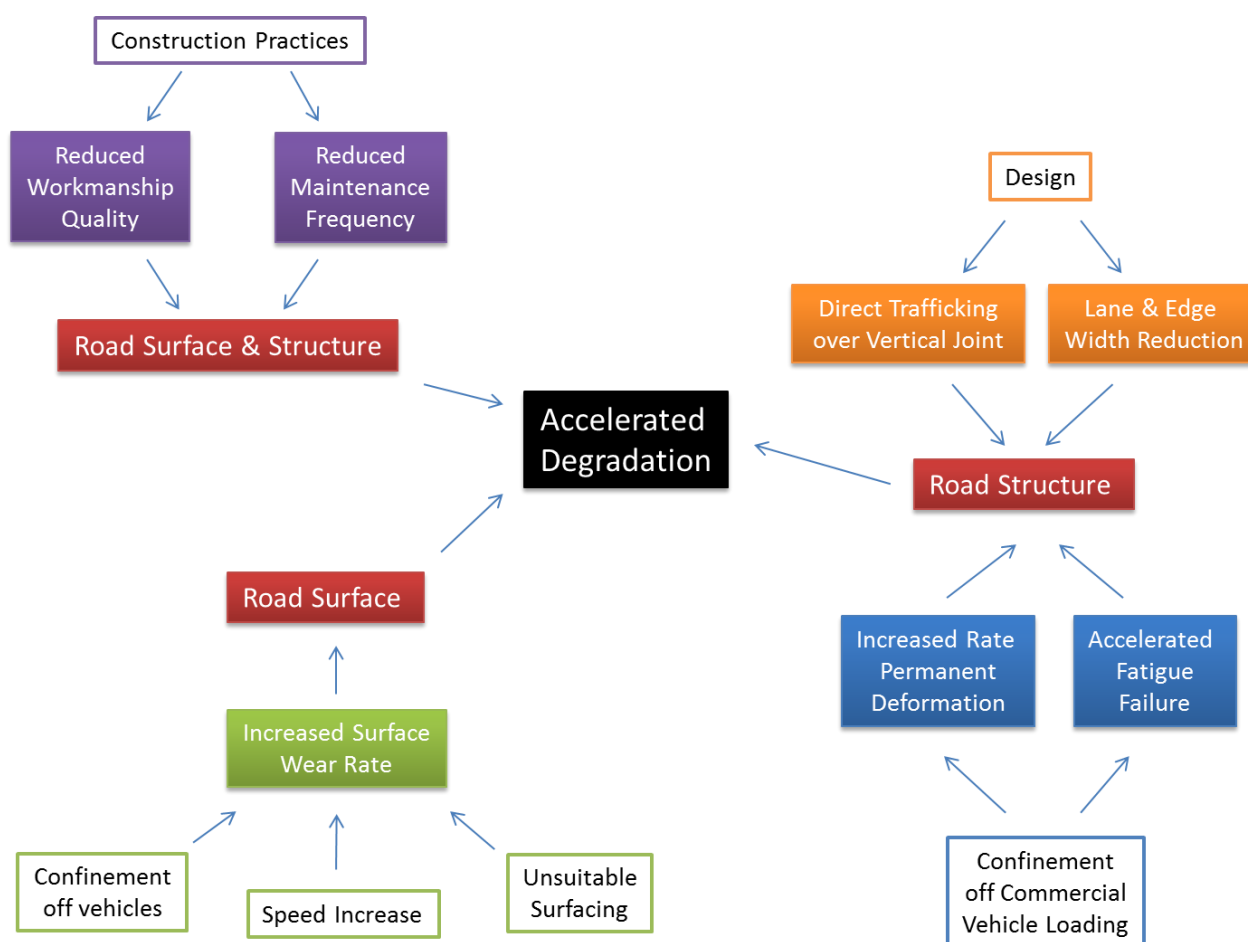


Figure 8. Accelerated degradation - Possible causes.

In the following chapters, consideration is given to how vehicle confinement, speed variation, surfacing suitability, design, and construction practices can affect the road surface and structure.

## 6. Confinement of vehicle lateral wander

### 6.1. General

In chapter 4, it was suggested that differences in the road layout could be a reason that degradation rates are higher in the single lane sections.

Factors such as the proximity of central and side barriers, cross section design, and vehicle speed will influence driver behaviour and determine the amount of vehicular lateral wander.

### 6.2. Vehicle position surveys

#### Locations

To determine the extent of lateral wander, a series of vehicle position surveys were carried out on two barrier separated roads near Linköping, Sweden.

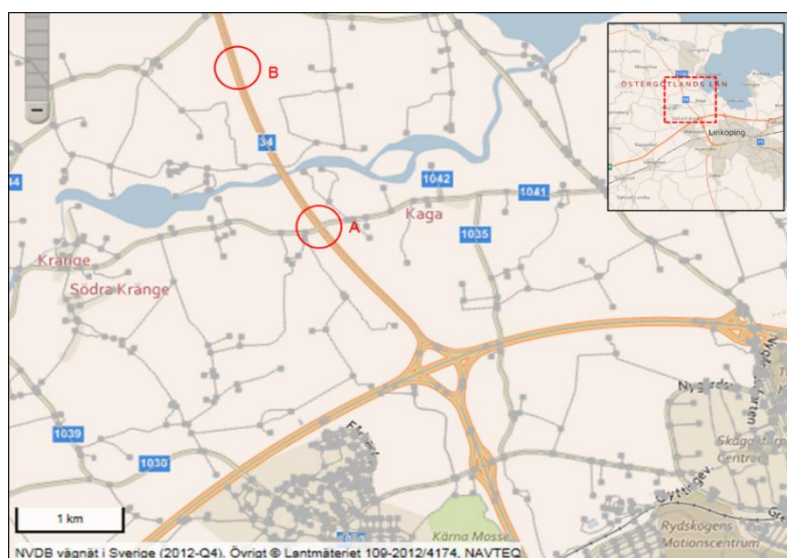


Figure 9. Survey locations on Road 34 (North of Linköping).

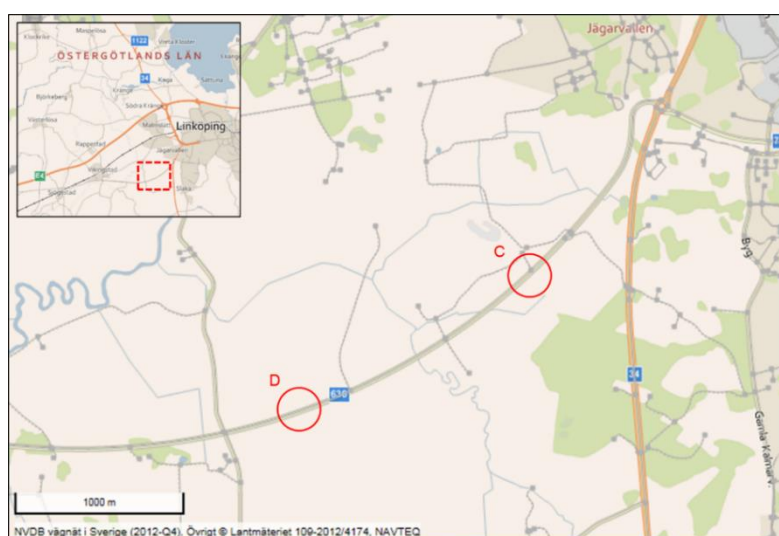


Figure 10. Survey locations on Road 636 (South-west of Linköping).

Measurements were taken in both directions at two locations on each road. This gave a total of eight survey points – four single lane sections and four double lane sections.

There were no junctions between the survey sites so the same traffic was recorded twice in each direction (for example at A2 and then at B1). However, a small number of vehicles were missed as a certain percentage will have used lane 2 in the double lane sections.

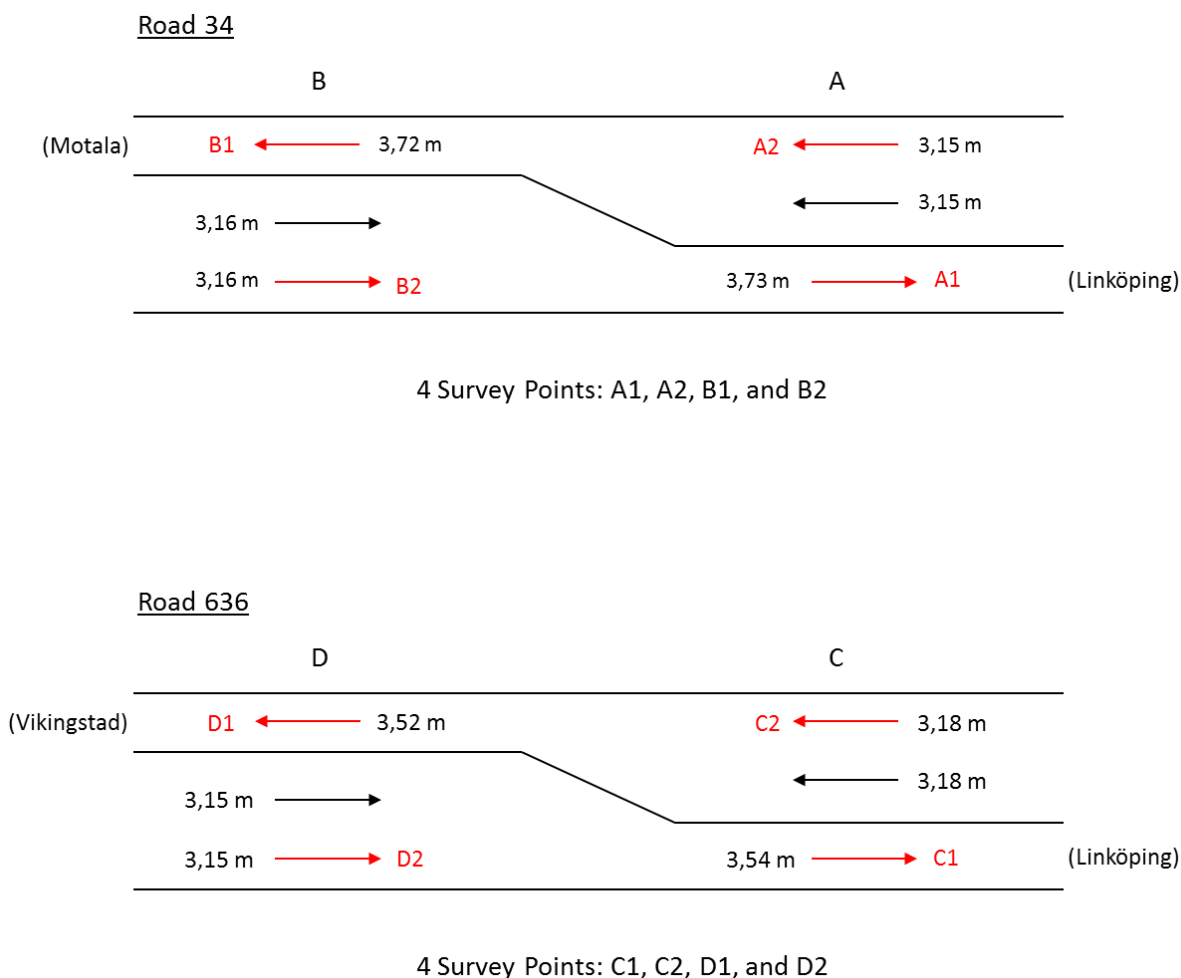


Figure 11. Position survey points (red arrow and text) and lane widths.

Using the survey data, it was possible to summarise the distribution of lateral position, average position, and variation of lateral position of approximately 270,000 vehicles.

The choice of measurement locations depended on several factors. Close proximity to VTI's Linköping office was an advantage as the measurement equipment required frequent monitoring. It was considered important to capture the same traffic between locations A to B and C to D, so there were no 'on off' intersections between measurement locations. It was also very important to consider the safety of those who would install, maintain and remove the measurement equipment. Each measurement location was adjacent to a lay-by which allowed for the safe parking of a vehicle. Installation and removal of the equipment was carried out during off peak hours and with physical protection from a TMA vehicle. Work at the single lane locations was carried out under temporary closures.

## Measurement Method and Technique

In the 1980s, VTI's measurement laboratory developed a unique traffic measurement system that recorded vehicle side position and gauge. Since then, the technique has been refined and updated and provides accurate position data.



Figure 12. Co-axial cable sensor (Photo. Terence McGarvey)

The system uses three coaxial cables which are fixed to the road surface in a Z type formation. Start, diagonal and stop cables are required. Distance between start and stop cables is 5 m and the diagonal cable is laid at a 45° angle to the start cable.

When a tyre runs over a cable, a triboelectric effect happens and electron migration occurs in the cable. This charge is then amplified and converted to a voltage pulse. Timings of voltage pulses are stored in a traffic analyser, type TA89, and then transferred to a computer for further analysis. The analysis programme used is PREC95 (Anund and Sørensen, 1995).



Figure 13. Traffic analyser TA 89 and charge amplifier (Photo. Terence McGarvey).

### Average position and standard deviations

In previous work (McGarvey, 2016), it has been shown that position data can be used to describe the distribution of a vehicles lateral position. Density curves were symmetrical and had distinctive bell shapes. This is consistent with normal distribution and means that standard deviation values are a good indicator of lateral wander. By applying the three-sigma rule, it can be assumed that nearly all vehicle positions will be contained within three standard deviations of the average position.

From the survey data, average position and standard deviations were determined. These were then used to describe the variation of lateral position, or lateral wander, for two vehicle categories:

- light vehicles (LV)
- commercial vehicles (HGV)

Table 3. Average position standard deviations.

Road	Survey Point	Std Dev		Std Dev		Lane Width (m)
		Front Left Wheel (mm)		Front Right Wheel (mm)		
		LV	HGV	LV	HGV	
34	A2	320	250	325	285	3.15
	B1	270	240	270	235	3.75
34	B2	375	255	375	285	3.15
	A1	255	205	265	245	3.75
636	D2	400	265	400	300	3.15
	C1	265	225	265	230	3.50
636	C2	365	270	355	265	3.15
	D1	255	225	260	230	3.50

From these results, it can be concluded that:

- HGV values were lower than LV values
- Both vehicle categories had lower values in the single lane sections
- Lane widths were greater in the single lane sections
- Slightly higher values can be observed in the 3.75 m wide single lane (compared to 3.5 m wide single lane)
- Values may be influenced by the total width (between road edge and central barrier) rather than just lane width

Table 4. Summary of standard deviations.

Lane	Lane Width (m)	Lateral Position Std Dev (mm)	
		Light vehicle	Commercial Vehicle
Lane 1 (d)	3.15	365	270
Lane 1 (s)	3.50	260	225
Lane 1 (s)	3.75	265	230

Note: Lane 1 (d) = lane 1 in the double lane section, Lane 1(s) = lane 1 in the single lane section.

### Comparisons with other road types

Position surveys were also carried out on sixteen conventional road types (Appendix 4). In addition, data was collected from motorway survey sites near Linköping and Uddevalla (Appendix 5), and from a 1+1 road type (Appendix 6) south of Linköping. Position data was calculated and compared with 2+1 road types. Results are summarised in the figures below.

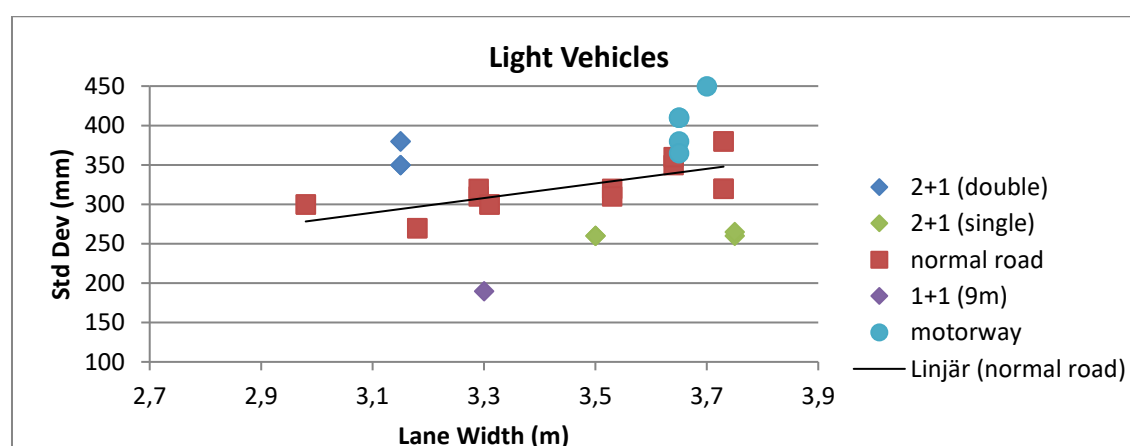


Figure 14. Average lateral position standard deviations.

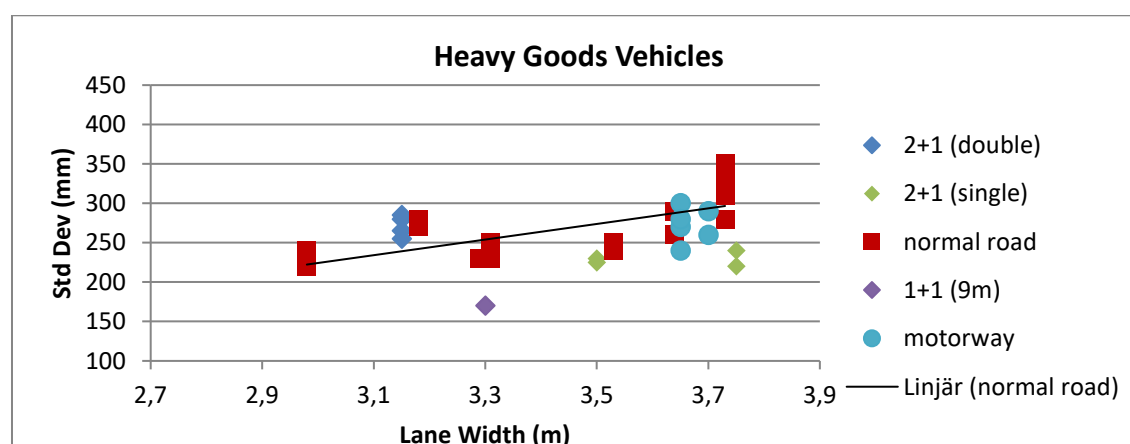


Figure 15. Average lateral position standard deviations.

It was assumed that increasing the lane width should increase the amount of vehicle lateral wander. This is confirmed in Figures 14 and 15 for normal road types (red square).

On the other hand, for 2+1 road types, there is actually a reduction in the amount of vehicle lateral wander in the wider single lane sections (green and blue diamond).

The amount of vehicle lateral wander in the 2+1 road double lane sections (blue diamond) was like motorway type roads (blue circle). Lane widths, however, were approximately 0.5 m narrower.

Vehicular lateral wander in 9 m wide 1+1 road types was extremely low (purple diamond).

### 6.3. Conclusion

The amount of vehicular lateral wander was determined by calculating how much vehicles deviate from their average lateral position. Confinement levels increase as standard deviation values reduce.

*Table 5. Comparison of road types and standard deviations of average lateral position.*

Road Type	Lane Width	Std Dev of Average Position (mm)	
		Light Vehicle	HGV
Normal (9 m)	3.65 m	350	285
2+1	3.15 m (double lane)	365 (+4%)	270 (-5%)
2+1	3.75 m (single lane)	265 (-24%)	230 (-19%)
1+1 (9 m)	3.30 m	195 (-44%)	175 (-39%)
Motorway	3.70 m	410 (+17%)	270 (-5%)

From the above table, vehicle confinement levels were similar for normal (9 m) and 2+1 (double lane section) type roads. Surface wear and deformation rates, regarding confinement, should therefore also be similar.

However, vehicle confinement increased in the single lane sections of 2+1 road types and on 1+1 road types. This suggests that accelerated degradation, attributed to vehicular confinement, only occurs in the single lane sections of the barrier separated road network.

As lane widths in single lane sections are generally wider than lanes in the double lane section, the increase in confinement must be influenced by either the close proximity of the central barrier or the total width between road edge and central barrier.



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## 7. Unsuitable surfacing

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### 7.1. Specification

The function of a road surface layer is to perform in accordance with the specified design. Traffic volume, studded tyre use, vehicle speed, lane width, and type of winter maintenance are examples of factors considered when specifying surfacing materials. Taking these factors into account, specification documents (Trafikverket, 2011) provide the following equation which can be used to calculate an adjusted traffic volume value -  $AADF_{k\text{ just}}$ .

$$AADF_{k\text{ just}} = AADF_k * J_{DD} * J_{SH} * J_{KF} * J_{VH}$$

Where:

- $AADF_k$  is the annual average daily flow per lane
- $J_{DD}$  is the adjustment factor for level of stud tyre use
- $J_{SH}$  is the adjustment factor for maximum speed limit
- $J_{KF}$  is the adjustment factor for road width or lane width
- $J_{VH}$  is the adjustment factor for type of winter maintenance (use of salt or not)

This value is then used to specify the correct type of surfacing and aggregate quality. (Trafikverket, 2013)

If there is a change to a roads original design, it is highly likely that some of these factors will be affected. In the case where a conventional road is converted to a barrier separated road, lane widths are likely to change. It is also possible that the maximum speed limit will be increased.

These changes can result in a higher adjusted traffic volume value and could necessitate an increase in specification standards. In certain circumstances, existing road surfacing materials will not meet the increased specification standard. The existing surface will therefore not be as suitable and will degrade at an accelerated rate.

For example, it is possible that the specification standard for aggregate abrasion values will increase when a conventional road is transformed into a 2+1 road. According to VTIs surface wear model (Appendix 7), a road surface aggregate with an aggregate abrasion value of 10 (required for an  $AADF_{k\text{ just}}$  between 1500 and 3500) will wear 30% more than a road surface aggregate with a value of 7 (required for an  $AADF_{k\text{ just}}$  between 3500 and 7000).

### 7.2. Conclusion

In certain cases, conventional roads may be widened to facilitate the extra lane required for 2+1 road type design. No resurfacing of the existing road surface or strengthening of the road structure will take place.

In certain circumstances, existing road surfacing materials will not meet the higher specification standard required for the roads new function. To avoid accelerated rates of surface wear, resurfacing with an appropriate surface course will be necessary.

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## 8. Vehicle speed increase

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### 8.1. Average speeds

Higher vehicle speeds of light vehicles using studded tyres increases the rate of surface wear (Jacobson and Wågberg, 2007). An increase in surface wear rate should therefore be expected if a higher speed limit has been introduced. It is also possible that variations in speed patterns, between single lane and double lane sections, could influence surface wear and deformation rates.

Using data from the position surveys, it was possible to determine average vehicle speeds for both single and double lane sections.

The data, summarised in Table 6, shows that there were certain patterns between single and double lane sections. For example:

- Commercial vehicles were driven at a constant speed through single and double lane sections, (for example from A2 (90 km/h) to B1 (89 km/h))
- Commercial vehicles were driven slightly slower on the sections with the 100 km/h speed limit (even though speeds were under the permitted limit)
- Light vehicles had a higher speed in the double lane sections, for example from A2 (107 km/h) to B1 (102 km/h). Differences were slightly more on the sections with the 110 km/h speed limit
- Corresponding speeds (for example, at sites A2 and B2) are nearly identical

*Table 6. Average Vehicle Speeds (refer to Figure 11 for position survey locations).*

Road	Location	Av Speed km/h Light Vehicle	Av Speed km/h Commercial Vehicle	Speed Limit km/h
34	A2	107	90	110
34	B1	102	89	110
34	B2	108	90	110
34	A1	101	89	110
636	D2	96	86	100
636	C1	92	85	100
636	C2	96	86	100
636	D1	93	85	100

### 8.2. Surface Wear

Jacobson and Wågberg (2007) demonstrated that higher vehicle speeds increase the rate of surface wear caused by studded tyres. It is estimated that a 5 km/h increase in speed will increase surface wear

by approximately 6%. However, an unknown number of light vehicles will be driven in lane 2 of the double lane section. Depending on the number of vehicles, this increase in actual surface wear will be distributed between the two lanes.

### 8.3. Commercial Vehicles

In Table 6 average speeds are consistent through both single and double lane sections. It can also be assumed that most of the commercial traffic will be driven in lane 1 of the double lane sections. This means that the effect commercial vehicles have on deformation rates, with regards to vehicle speed, should be similar in both single and double lane sections.

### 8.4. Conclusion

Differences between “before and after conversion” average vehicle speeds will influence the amount of surface wear.

Double lane sections have a slightly higher light vehicle average speed than single lane sections. Total surface wear in the double lane section could be around 6% higher than in the single lane section. However, a portion of this increase will occur in lane 2.

If an increased speed limit has been introduced, for example from 90 km/h to 100 km/h, then an additional increase in surface wear should also be expected.

The effect commercial vehicles have on deformation rates, with regards to vehicle speed, should be similar in both single and double lane sections.

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## 9. Design

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### 9.1. Design guidelines

Conventional 13 m wide roads can be converted to barrier separated roads without the need for widening. Alternatively, narrower roads can be widened to 14 m to accommodate the extra traffic lane. New build sections should be 14 m wide.

Design standards are described in the publications *Krav och råd för vägars och gators utformning* (Trafikverket, 2015). According to standards there are various typical sections that should be used for barrier separated road type design:

- Conversion of existing 13 m road, with or without pedestrian and cycle usage
- New build and widening of existing road less than 13 m with or without pedestrian and cycle usage
- Conversion of existing 13 m road, with or without pedestrian and cycle usage, and with limited double lane sections

Depending on the standard, typical lane widths can be either 3.25 m or 3.50 m for the double lane sections and 3.50 m or 3.75 m for the single lane sections. Verge widths can vary between 0.50 m and 1.0 m. Widths between the central barrier area (300 mm wide) and offside lane edge can vary between 0.45 m and 0.95 m.

For 1+1 sections, suggested lane widths are 3.25 m, 3.50 m or 3.75 m. Verge widths can vary between 0.50 m and 0.75 m. Widths between the central barrier area (300 mm wide) and offside lane edge can vary between 0.35 m and 0.60 m.

It should be noted that the verge width and width between the central barrier and offside lane edge contain the painted markings which are typically between 0.20 m and 0.30 m wide.

### 9.2. Longitudinal alignment

In Figure 16, typical 2+1 road type design options are detailed.

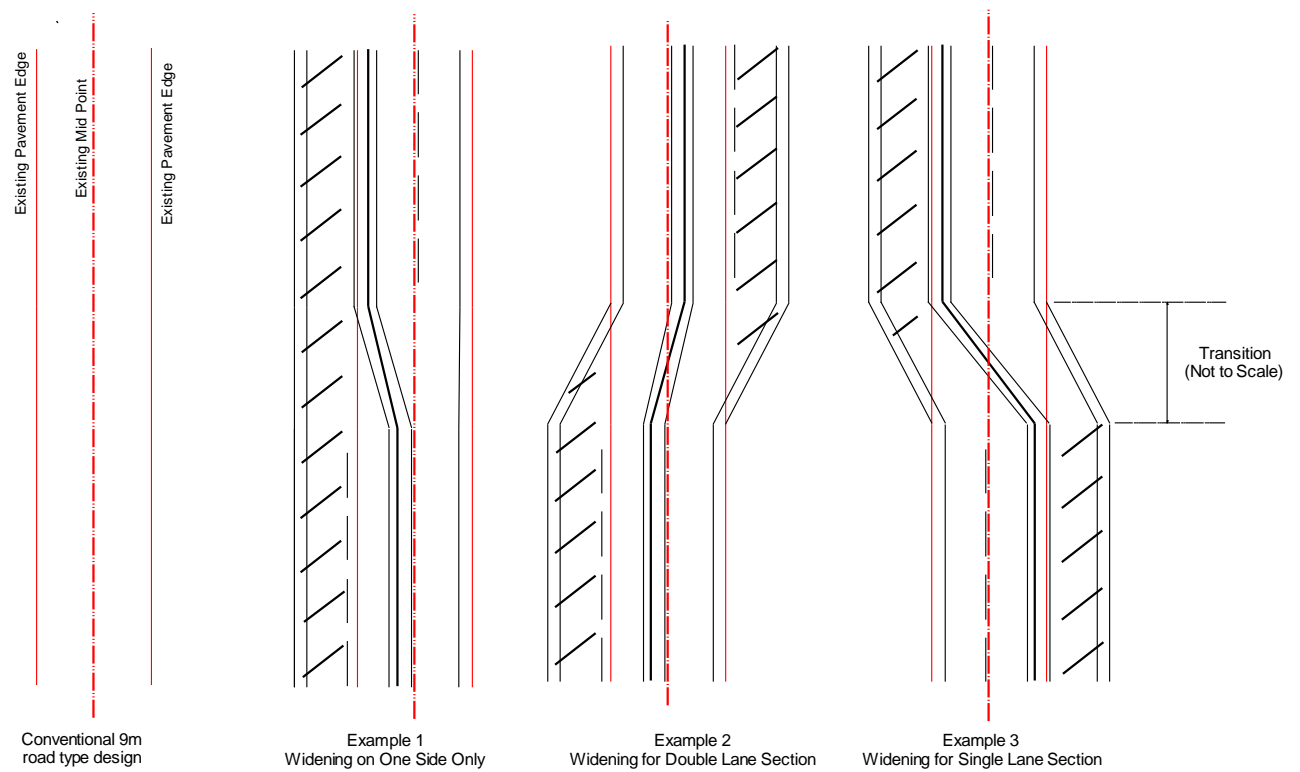
Widening of the existing road can be carried out in three different ways:

- Example 1 - Widening on one side only
- Example 2 - Widening to accommodate lane 1 of the double lane sections
- Example 3 - Widening to accommodate the single lane sections

Each method will have an effect on where the longitudinal joints will occur. Positioning is very important and must be considered at the design stage in order to avoid or minimise direct trafficking over the joints.

From a driving point of view, Example 1 (Figure 16) will provide a better longitudinal design. Vehicles can flow smoothly between single and double lane sections. Examples 2 and 3 require vehicles driving in lane 1 to manoeuvre right and left at the transition sections.

In terms of construction, Example 1 is the simpler method as widening will only be required on one side. In addition, drainage lines on the non-widened side will remain undisturbed



*Figure 16. Longitudinal design options.*

In the above figure, the existing road plan profile is detailed by the red lines. The options to widen the road are shown in black in examples 1, 2 and 3. The hatched area indicates the new widened section.

## 10. Construction

### 10.1. Road widening

VGU advises that roads narrower than 13 m wide should be widened to 14 m to accommodate the extra traffic lane. Widening techniques, Figure 17, can be classed as either symmetrical or asymmetrical. The examples show equal pavement widths either side of the crown-point (mid-point) and this is normal for conventional road type design.

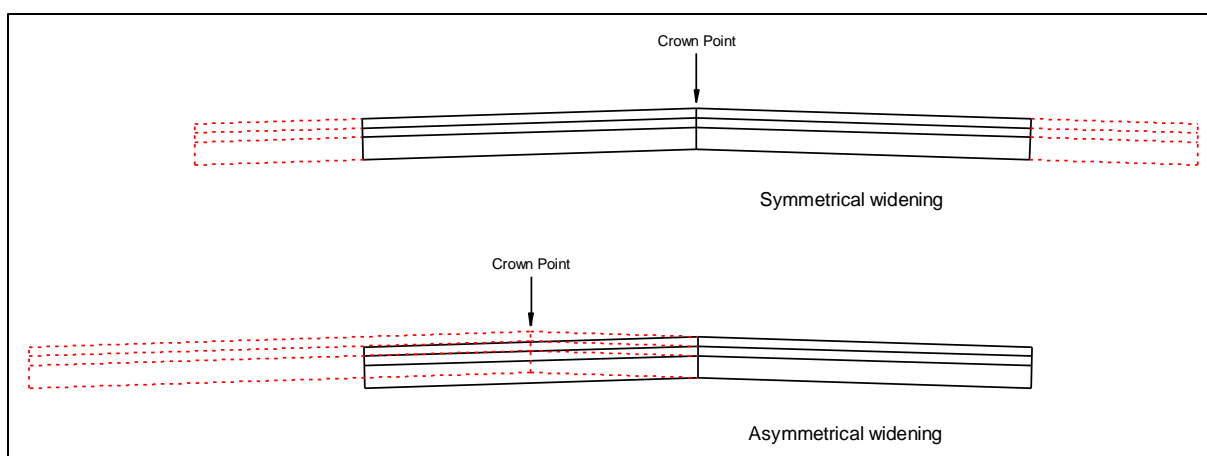


Figure 17. Symmetrical and asymmetrical widening – Conventional road type.

A barrier separated road design, however, requires unequal pavement widths either side of the crown-point. In addition, the position of the crown-point will vary when the road changes between single and double lane sections. This is shown in the section examples detailed in Figure 18.

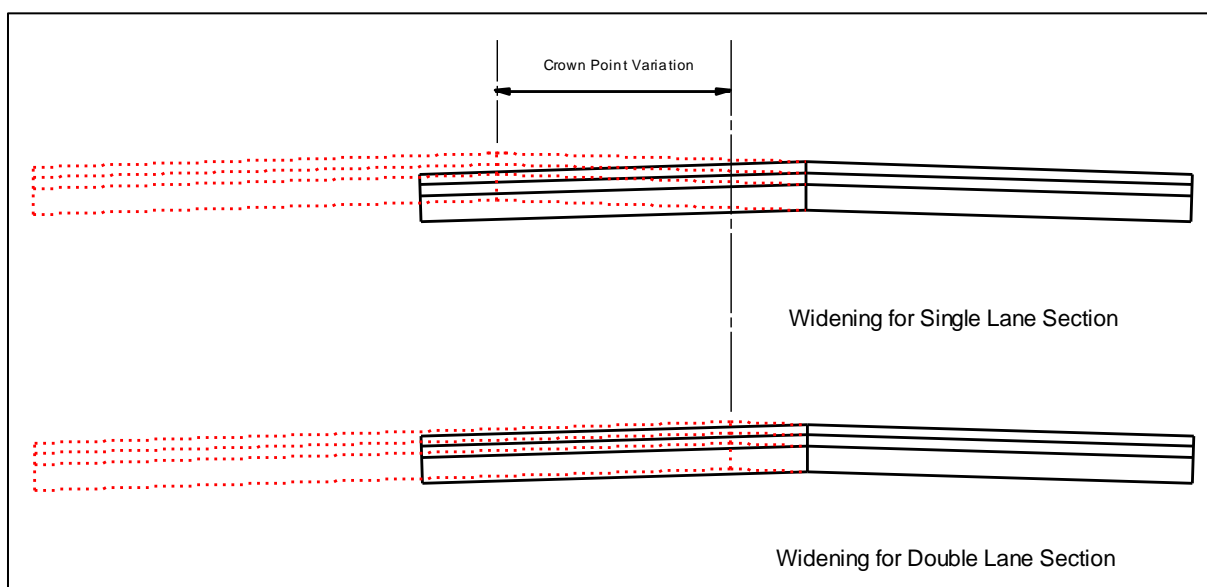


Figure 18. Widening – 2+1 road type.

## 10.2. Transition Points

Problems with construction quality can be experienced at the transition points between single and double lane sections. Transitions will often narrow down to near zero at the tie-in point. Examples of these weak problem areas are detailed in Figures 19 and 20.

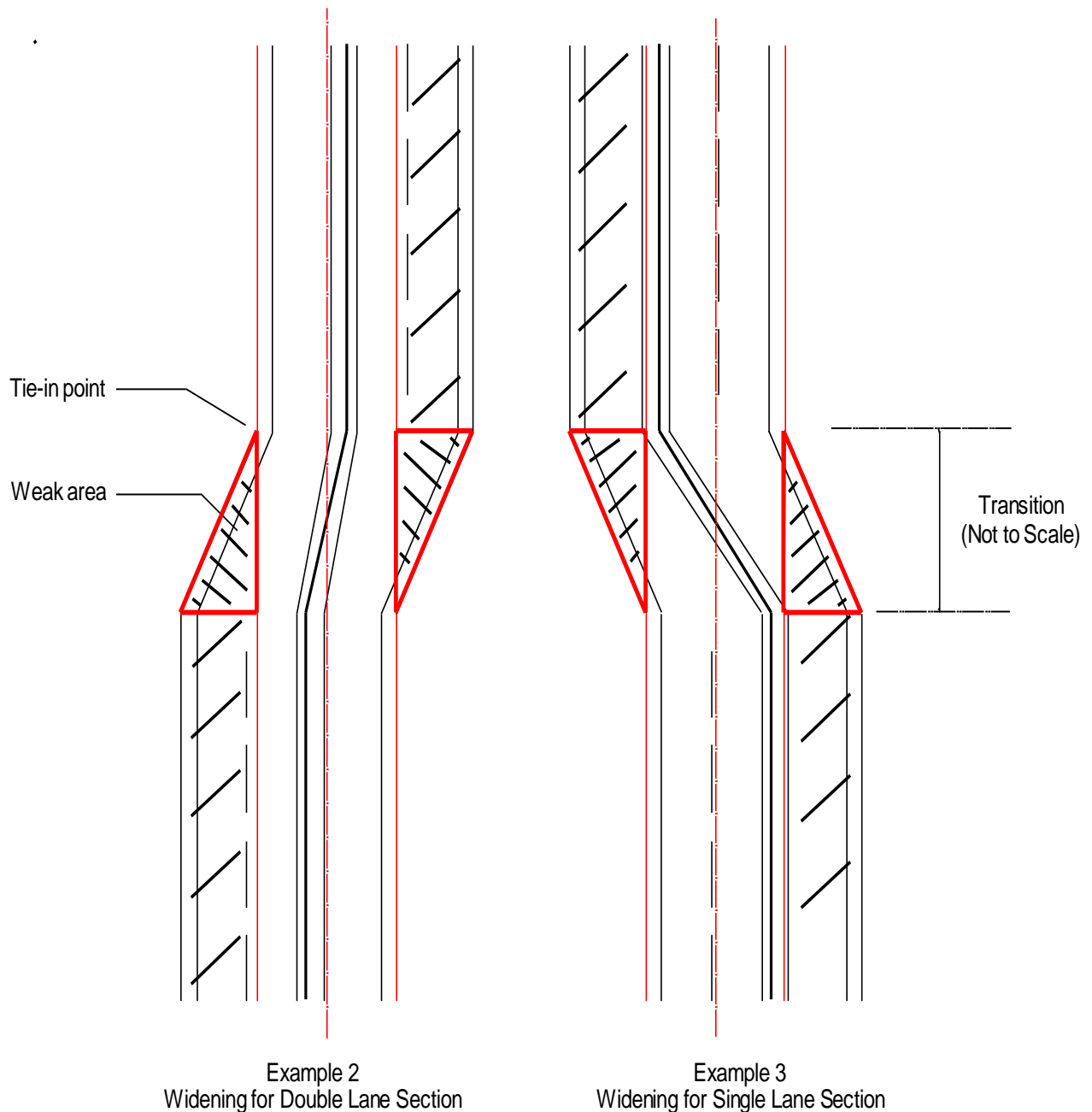
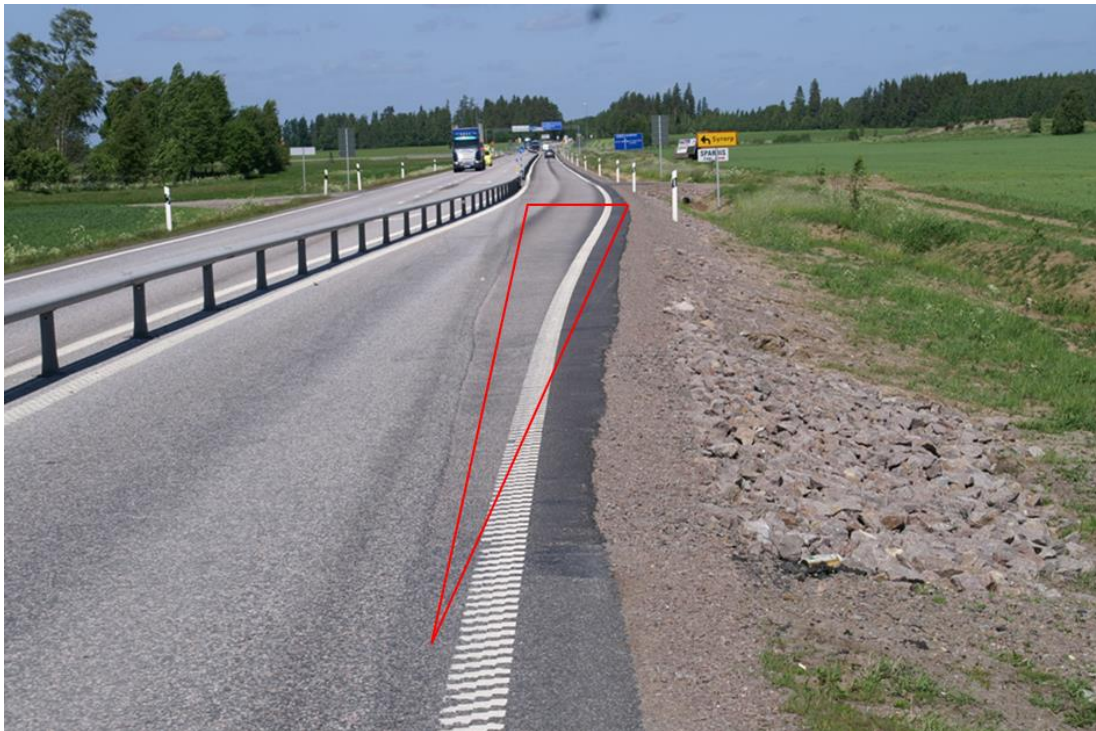


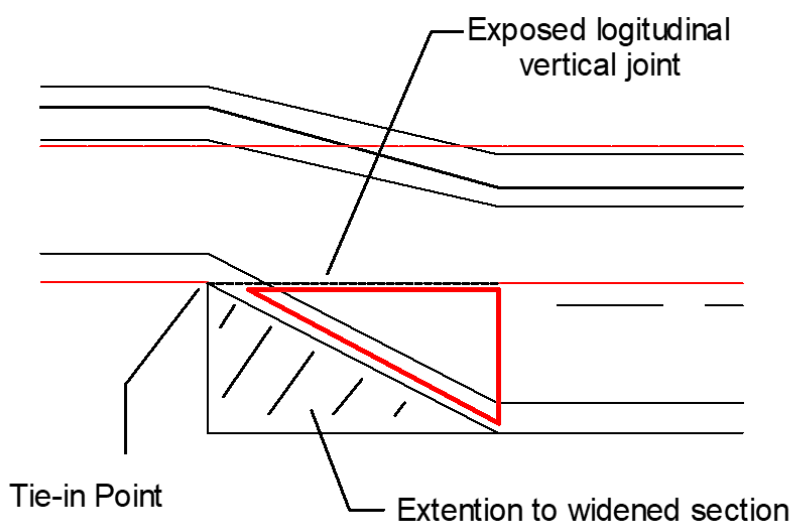
Figure 19. Weak transition points – Plan view. Hatched marking indicates new widened section



*Figure 20. Weak transition point (Photo. Terence McGarvey).*

Narrow lengths of road pavement will often be structurally weaker than full width sections as it is very difficult to achieve laying consistency and satisfactory levels of compaction. These areas are likely to degrade quicker than the full width sections.

A possible solution, Figure 21, would be to extend the widened section up to or beyond the actual tie in point. However, further consideration must be given to the longitudinal vertical construction joint which will be exposed to traffic.



*Figure 21. Design improvement.*



An option would be to introduce a transverse vertical joint, J1, and hatched road markings. Transverse joints are easier to construct and the road markings would prevent traffic driving over the longitudinal joint, J2.

The following figure describes how to achieve this when existing surface courses are being retained. The method can be easily modified if an overlay of the existing surface course is planned.

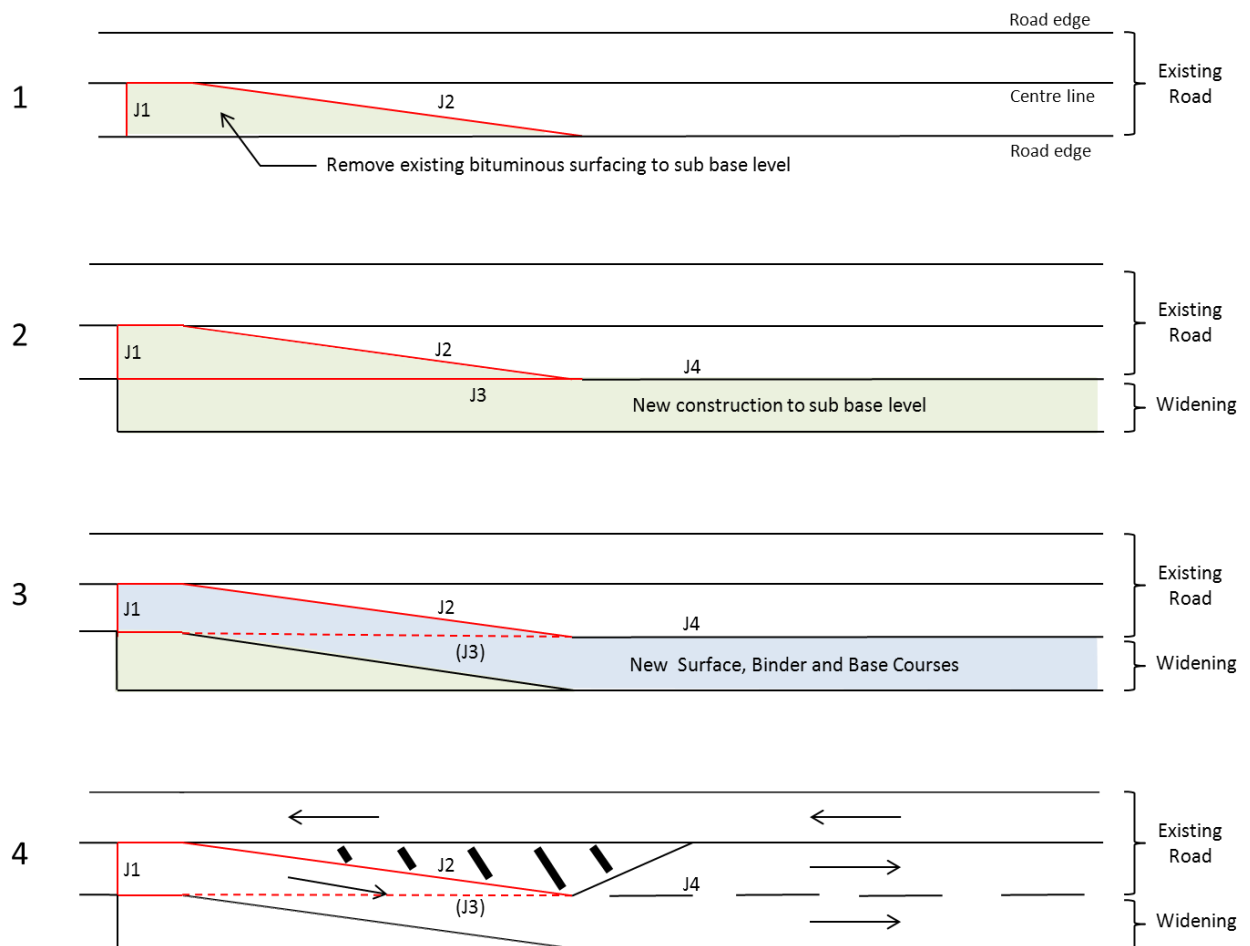


Figure 22. Revised construction method.

Longitudinal joint, J3, will still be subjected to traffic loading but will be protected to a certain extent by the surface, binder and base courses.

Construction methods associated with the vertical interface between new and existing pavement construction (longitudinal joint - J4) are discussed in the next chapter.

### 10.3. Interface between new and existing construction

Vertical interfaces between new and existing construction are considered to be weak points in the road structure. The vertical joint along the existing road crown-point can also be considered as a potential weak point. Ideally, vertical joints should be constructed out-with vehicle wheel tracks; however, this may prove to be difficult for certain recommended section designs.

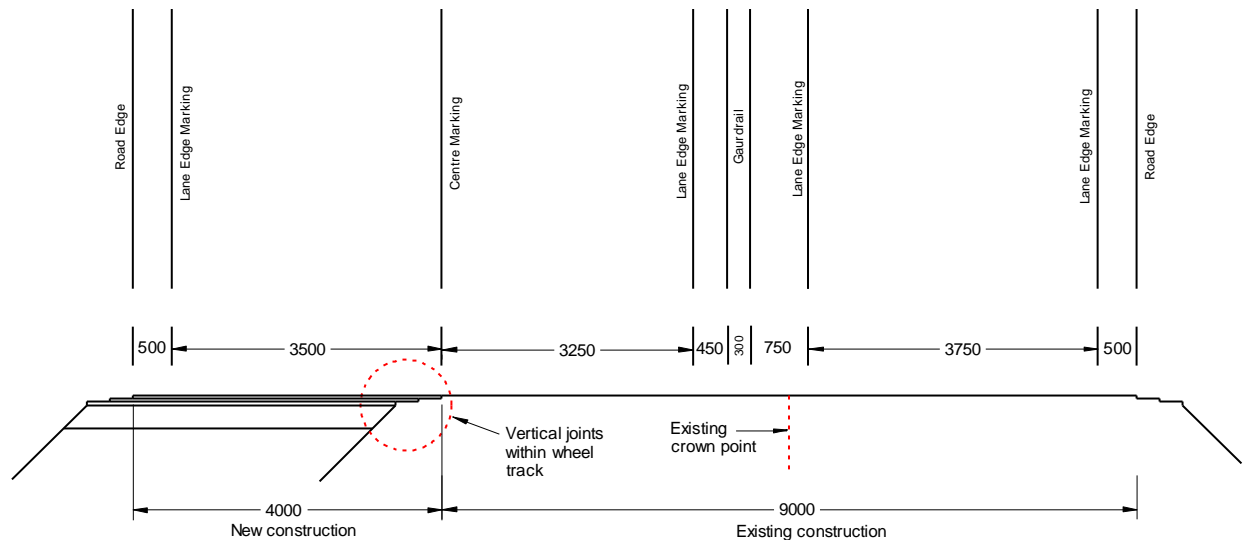


Figure 23. Widening from 9 m to 13 m (without cycle and pedestrian use).

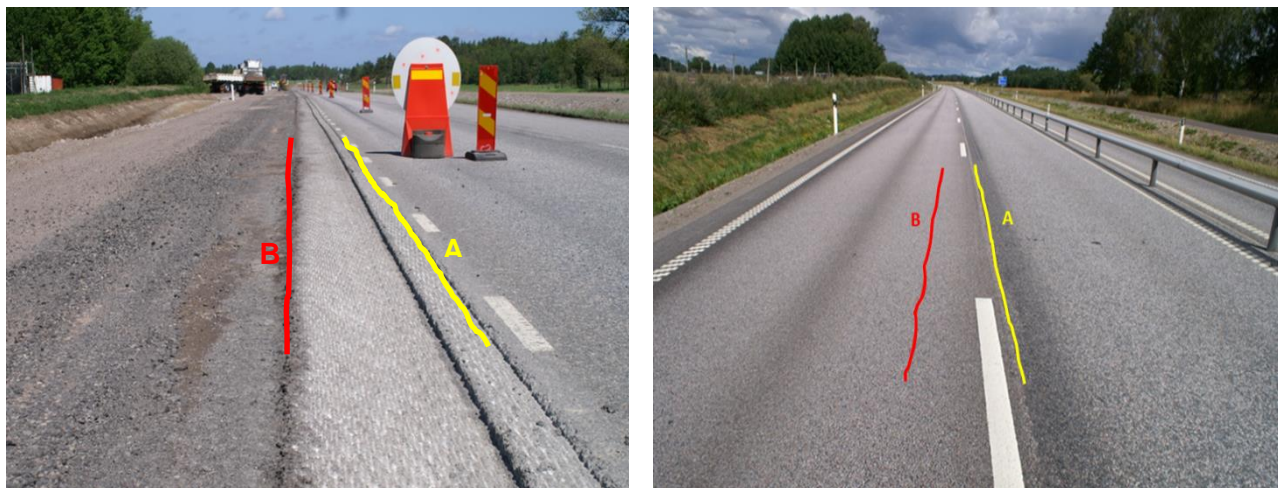


Figure 24. 2+1 project – Vertical joint positions (A+B) during and after construction (Photo. Terence McGarvey).

It can be seen in Figures 23 and 24 that vertical joint positions can be constructed in or close to vehicle wheel paths and are therefore likely to be subjected to direct trafficking.

To try and improve cross section design, consideration must be given to where in the road vehicles drive. This can be achieved by plotting vehicle average positions and standard deviations.

## 11. Vehicle Position

### 11.1. Plotting vehicle position

To confirm where vehicles are driven in a lane, data from the vehicle lateral position surveys was used to map vehicle front tyre average positions and associated standard deviations. As tyre contact widths were unknown, widths of 175 mm (205 tyre size) for light vehicles, and 265 mm (295 tyre size) for heavy vehicles have been assumed and used in the calculations.

Normal distributions are symmetric and have bell-shaped density curves with a single peak. This is like the distribution pattern observed with vehicle position (Appendix 8). Two quantities must be specified: the mean ( $\bar{x}$ ), where the peak of the density occurs, and the standard deviation ( $s$ ), which indicates the width of the curve.

The example below (Figure 25), shows how average positions ( $\bar{x}$ ) and standard deviations ( $s$ ) can be used to estimate the probability of where in the road a particular group of vehicles are driven.

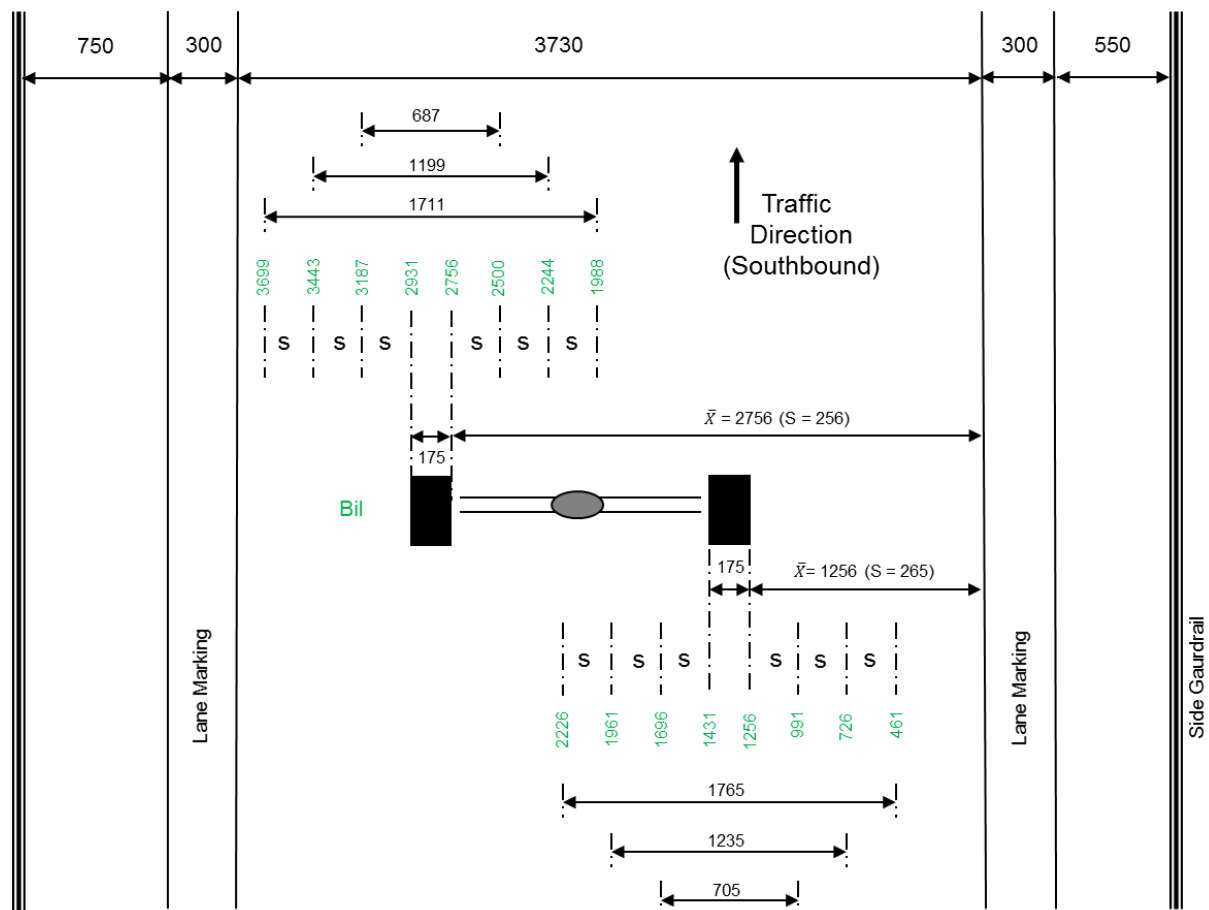


Figure 25. Distribution of light vehicle position. (McGarvey, 2016)

By applying the three-sigma rule, it can be assumed that nearly all tyre positions will be contained within three standard deviations of the average tyre position. The example above shows that off-side tyre positions are confined within a 1 711 mm band width. Near-side tyre positions are confined within a 1 765 mm band width.

## 11.2. Surveyed average positions and standard deviations

The following scaled drawing examples show the average tyre positions (full line) and associated standard deviations (dash line). Green lines indicates light vehicles and blue lines indicates heavier commercial traffic.

### Example 1: Road 34 – Survey locations A1 and A2

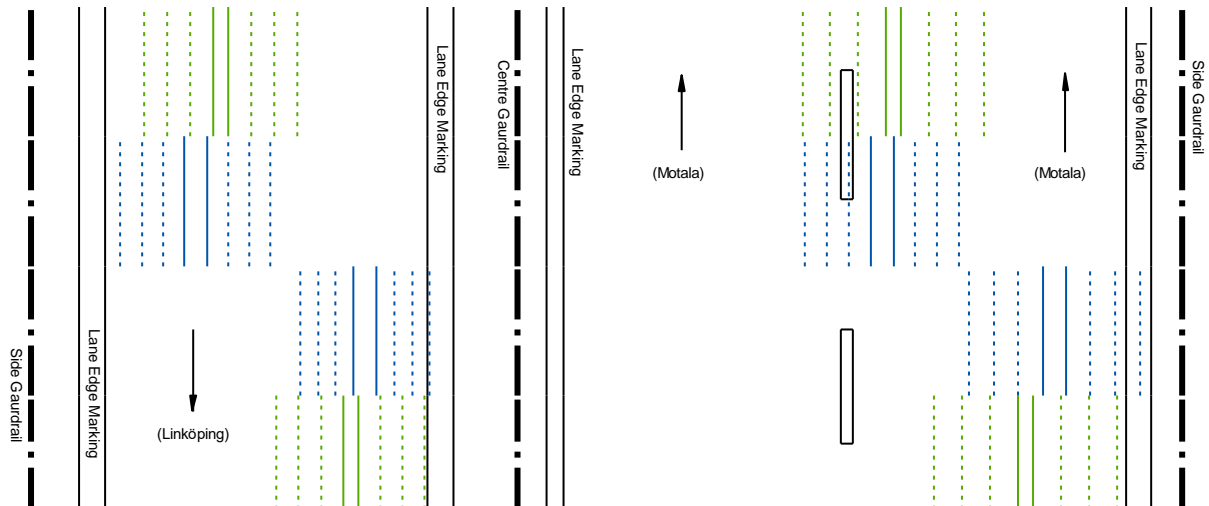


Figure 26. Road 34 - Survey locations A1 and A2.

In this case, the presence of side guard rail, on both sides, has pushed the traffic position to the left.

Almost all traffic in the single lane section (within three standard deviations) was confined within the traffic lane.

A large percentage of traffic in the double lane section was positioned close to the mid-point between the two lanes.

Lateral wander was much more confined in the single lane section.



Figure 27. Road 34 - Survey locations A1 and A2 (Photo. Terence McGarvey).

## Example 2: Road 34 – Survey locations B2 and B1

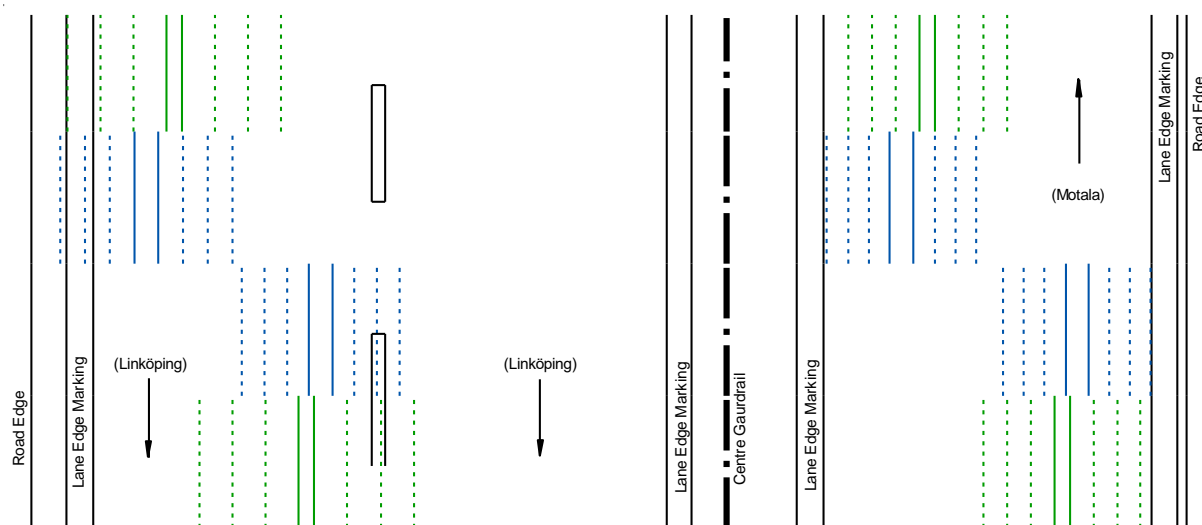


Figure 28. Road 34 - Survey locations B2 and B1.

The above example shows that the narrow verge width has pushed traffic in the single lane section to the left. Almost all traffic was confined within the lane width.

Traffic position in the double lane section was very central. A smaller percentage of traffic, compared with locations A1 and A2, was positioned over the mid point of the two lanes and over the side lane edge marking and verge.

Lateral wander was much more confined in the single lane section.



Figure 29. Road 34 - Survey locations B2 and B1 (Photo. Terence McGarvey).



### Example 3: Road 636 – Survey locations C1 and C2

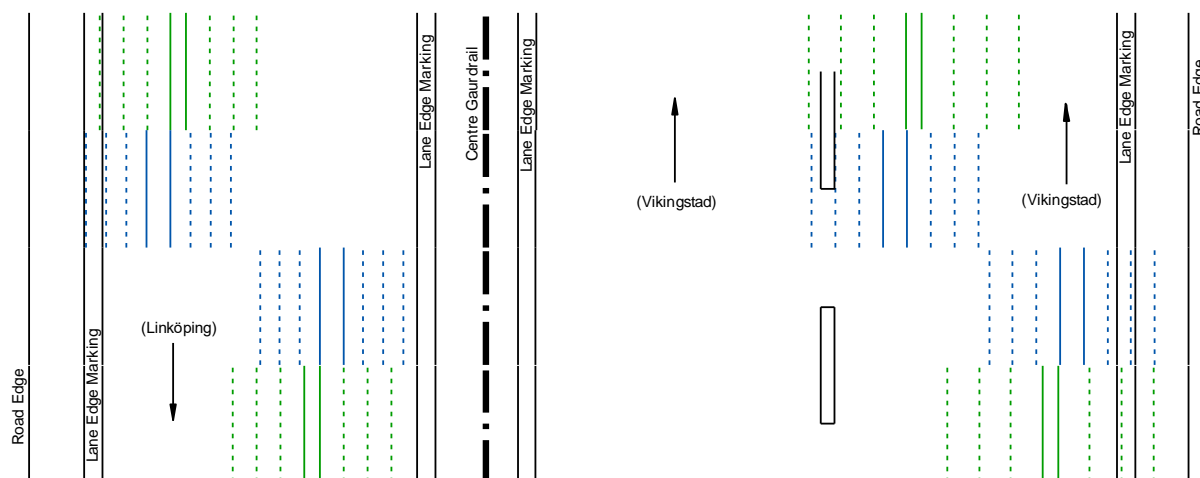


Figure 30. Road 636 - Survey locations C1 and C2.

Here, traffic was positioned slightly to the right in the double lane section. A small percentage of traffic was positioned over the mid point of the two lanes.

Traffic position in the single lane section was also right of centre. A small percentage of vehicles were positioned over the side lane edge marking.

Lateral wander was much more confined in the single lane section.



Figure 31. Road 636 - Survey locations C1 and C2 (Photo. Terence McGarvey).

#### Example 4: Road 636 – Survey locations D2 and D1

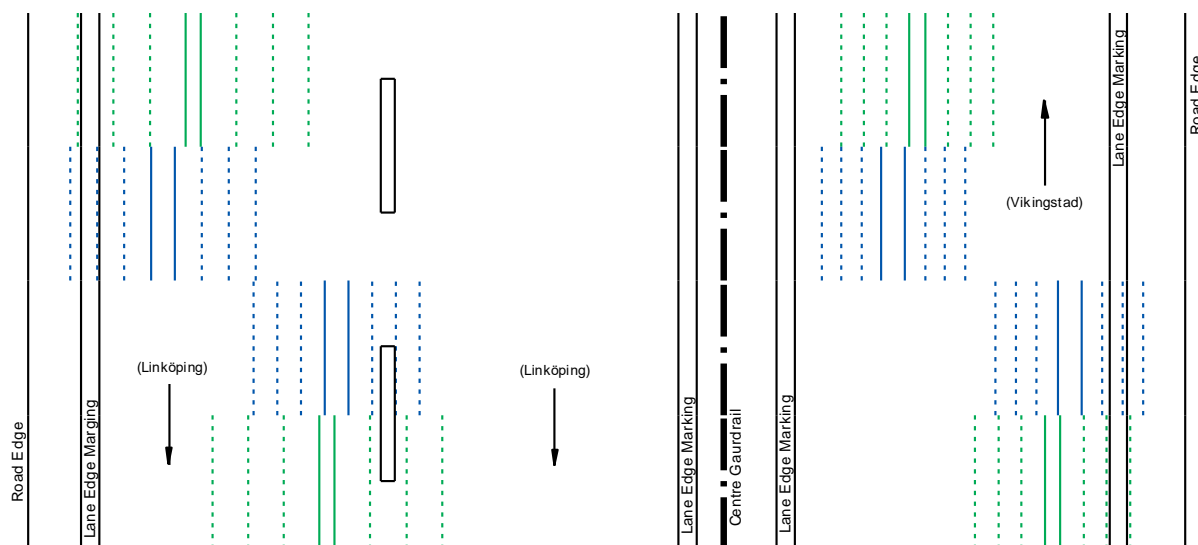


Figure 32. Road 636 - Survey locations D2 and D1.

Traffic in the double lane section was positioned slightly to the left. A larger percentage of traffic, compared with location C2, was positioned over the mid point of the two lanes.

Traffic position in the single lane section was positioned right of centre. A larger percentage of traffic, compared with location D1, was positioned over the side marking and verge.

Lateral wander was much more confined in the single lane section.



Figure 33. Road 636 - Survey locations D2 and D1 (Photo. Terence McGarvey).

By comparing these vehicle position examples with typical cross section examples, it can be concluded that a significant number of vehicles will be driven over the longitudinal vertical joint interfaces formed between new and existing construction. To minimise the effect of this trafficking, improvements to the cross-section design must be made.

### 11.3. Wide side-verge example

An ideal barrier separated road design should provide sufficient lane and verge widths to minimise traffic confinement in the single lane sections. The design should also ensure that vertical joints, between the new construction and existing structure, are positioned out with vehicle wheel tracks.

The positive effect associated with a wide side-verge can be demonstrated in the following example. The road has been constructed with a wide side-verge along most of the single lane sections.



Figure 34. Road 22, Single lane section with wide side-verge (Photo. PMSv3, Trafikverket).

Comparisons of rut depth values showed that development rates are very similar in both single and double lane sections. This could indicate that the amount of vehicular lateral wander is similar in the single and double lane sections, and that no accelerated degradation is taking place.

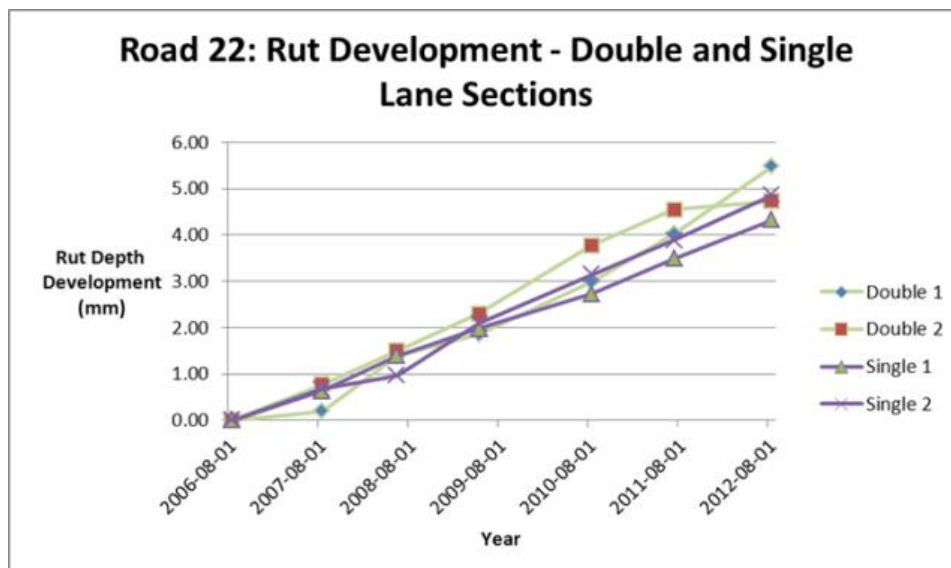


Figure 35. Road 22, Rut development in single and double lane sections.



## 11.4. Cross section design improvements

Using the vehicle position information described in chapter 11.1 as a template, it was possible to modify the typical cross sections recommended in VGU:

### Option 1: Widening for double lane section

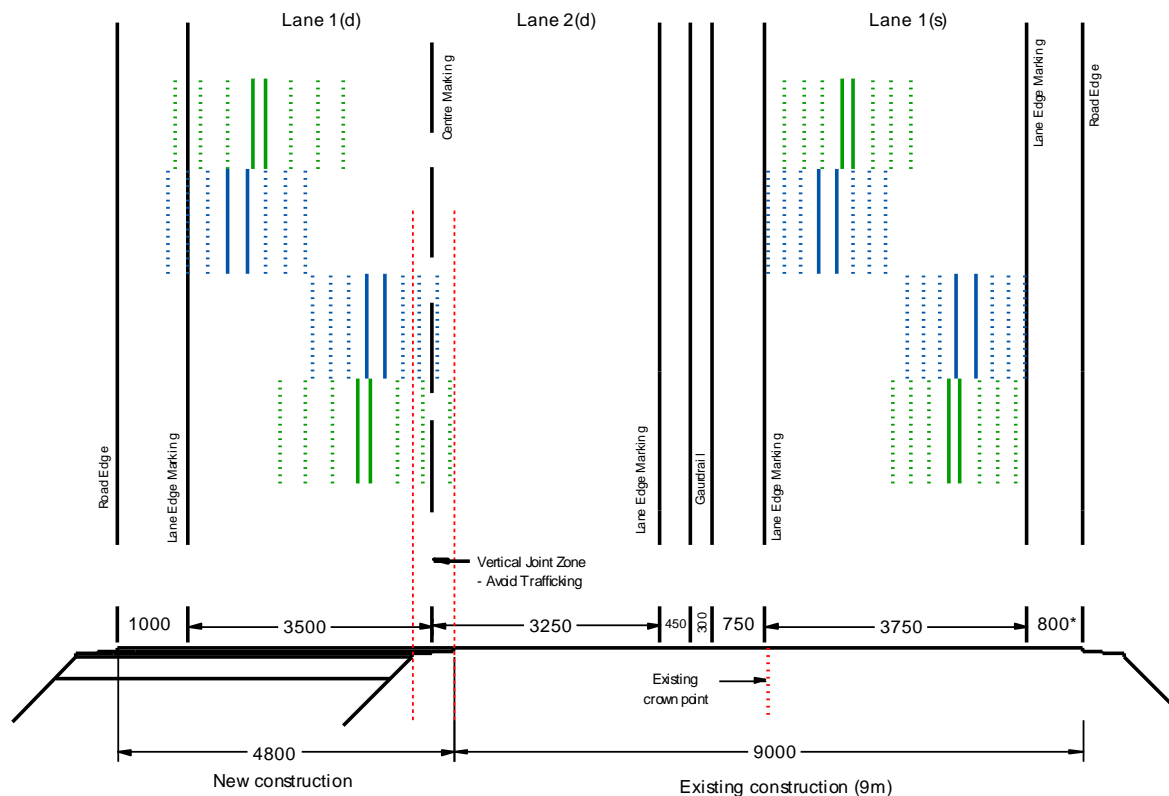


Figure 36. Option 1 – Widening for double lane section.

Typical distribution of wheel tracks (based on Road 34, survey locations B2 and B1):

- Light Vehicle Track (green) assuming a front tyre contact width of 175 mm
- Heavy Vehicle Track (blue) assuming a front tyre contact width of 265 mm

In this example, figure 36, the vertical joint at binder course level is placed between lanes 1 and 2 of the double lane section. Surface course and base course vertical joints will be formed 300 mm either side of this point. The existing width of 9.00 m is not sufficient to meet VGU recommendations, so a reduction in Lane 1(s) verge width\* (1.00 m to 0.80 m) is required. Alternatively, additional widening on this side will be necessary.

Proposed section widths = (1.00) (3.50) (3.25) (0.45) (0.30) (0.75) (3.75) (0.80\*) = 13.80 m

Wheel tracking in Lane 1(d) is positioned almost central, however, a significant number of heavy vehicles will still be driven directly over the vertical joint zone - the base course vertical joint is positioned between one and two standard deviations of the HGVs average position.

This design can be further improved in Option 2.

## Option 2: Widening for double lane section

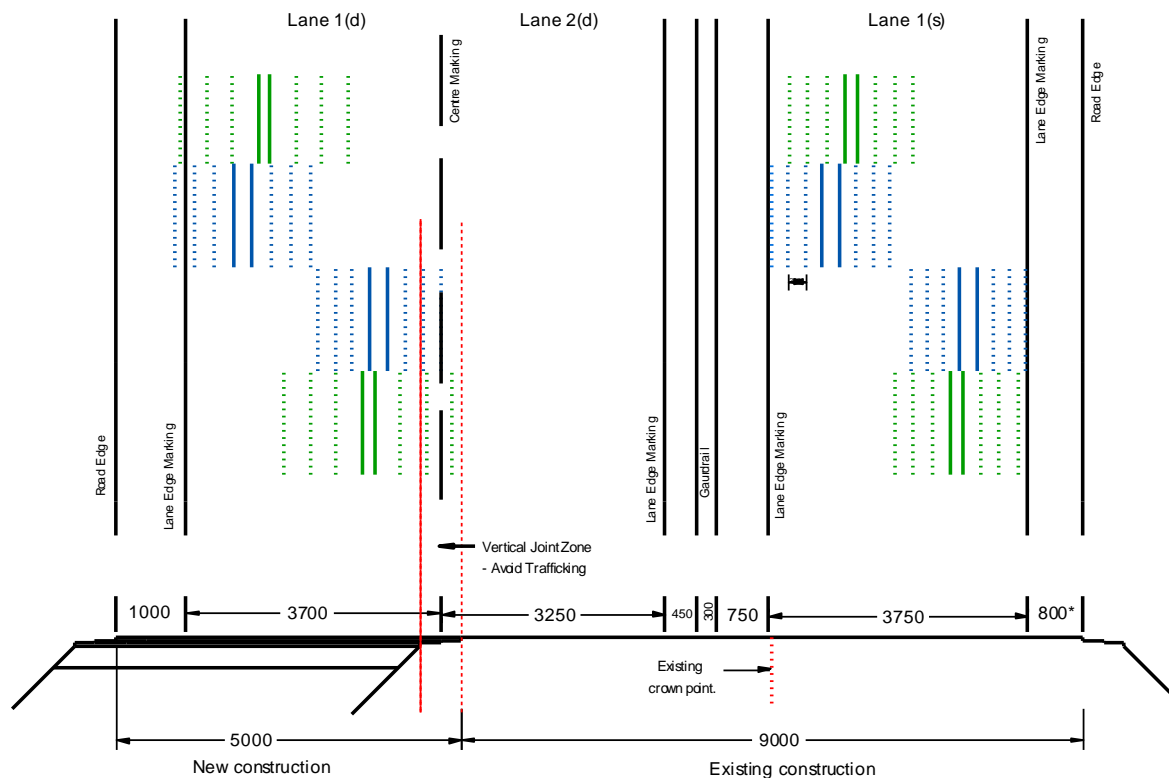


Figure 37. Option 2 – Widening for double lane section.

Typical distribution of wheel tracks (based on Road 34, survey locations B2 and B1):

- Light Vehicle Track (green) assuming a front tyre contact width of 175 mm
- Heavy Vehicle Track (blue) assuming a front tyre contact width of 265 mm

This example, figure 37, is similar to Option 1 apart from Lane 1(d) width which is increased by 0.20 m to 3.70 m.

Similarly, an existing width of 9.00 m is not sufficient to meet VGU recommendations, so a reduction in Lane 1(s) verge width\* (1.00 m to 0.80 m) is required. Alternatively, additional widening on this side will be necessary.

Proposed section widths = (1.00) (3.70) (3.25) (0.45) (0.30) (0.75) (3.75) (0.80\*) = 14.00 m

Assuming that the wheel track distribution in Lane 1(d) will remain the same and the central position is maintained, the vertical joint position at base course level will now be nearer to the second standard deviation point. This means that a lower percentage of HGVs will be driven over the vertical joint zone.

Comparisons with survey location B2 show an improvement of around one standard deviation.

### Option 3: Widening for single lane section

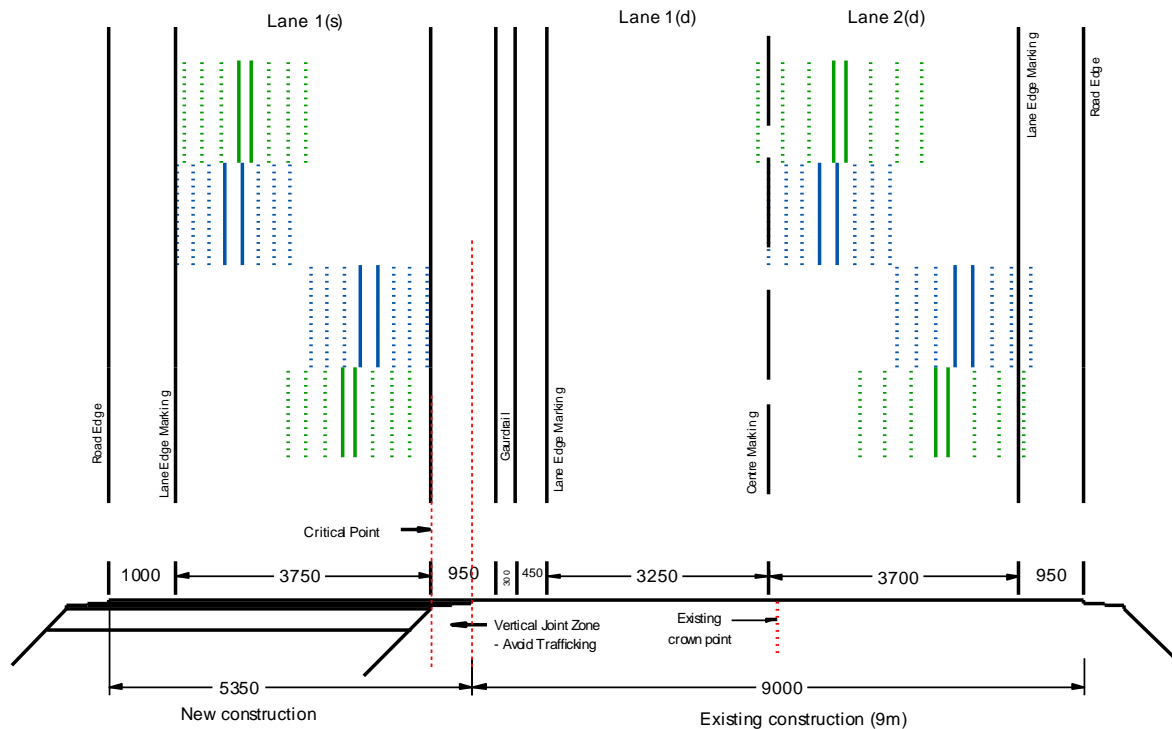


Figure 38. Option 3 – Widening for single lane section.

Typical distribution of wheel tracks (based on Road 34, survey locations B2 and B1):

- Light Vehicle Track (green) assuming a front tyre contact width of 175 mm
- Heavy Vehicle Track (Blue) assuming a front tyre contact width of 265 mm

In this example, figure 38, the base course vertical joint is placed at the edge of Lane 1(s).

Assuming an existing width of 9.00 m, the total width would be 14.35 m.

Proposed section widths = (1.00) (3.75) (0.95) (0.30) (0.45\*) (3.25) (3.70) (0.95\*) = 14.35 m

\*Widths can be adjusted to ensure that existing crown-point is positioned between Lane 1(d) and Lane 2(d)

### Option 4a: Combined single and double lane design

A combination of design options 2 and 3 could provide an ideal solution with regards to placement of joints. This would result in varying road width between 14.00 m and 14.35 m, however, the 1.00 m wide verge in design option 2 could be widened to 1.35 m to give a constant 14.35 m construction width. The single lane section (bottom right in Figure 39) is however restricted to 5.30 m.

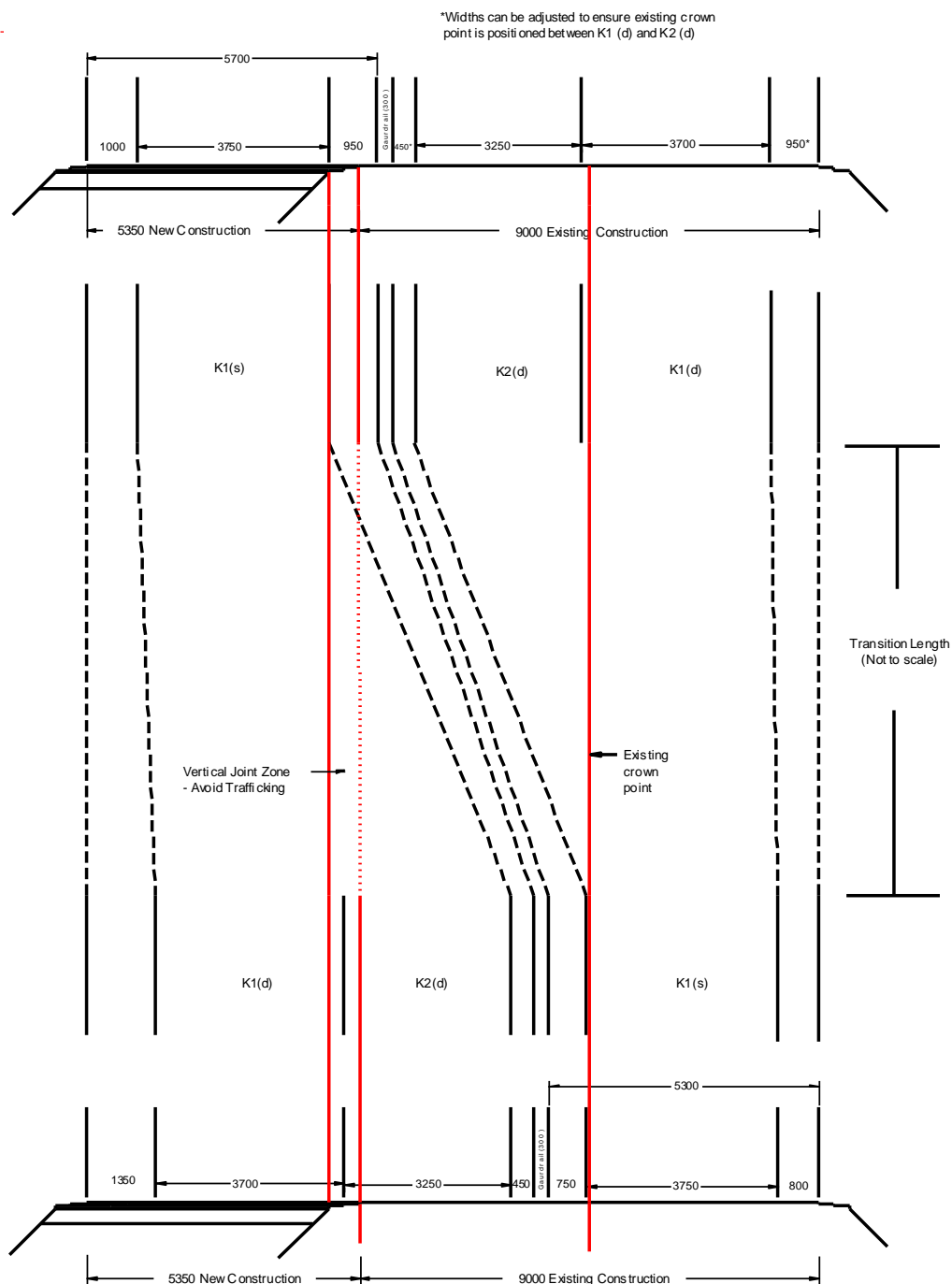


Figure 39. Option 4a – Combined single and double design.

### Option 4b: Combined single and double lane design

To widen the single lane section (bottom right in Figure 40), the vertical joint zone between new and existing construction can be moved further into lane 2 of the double lane section. As most vehicles in lane 2 are likely to be light vehicles, this may be an acceptable compromise.

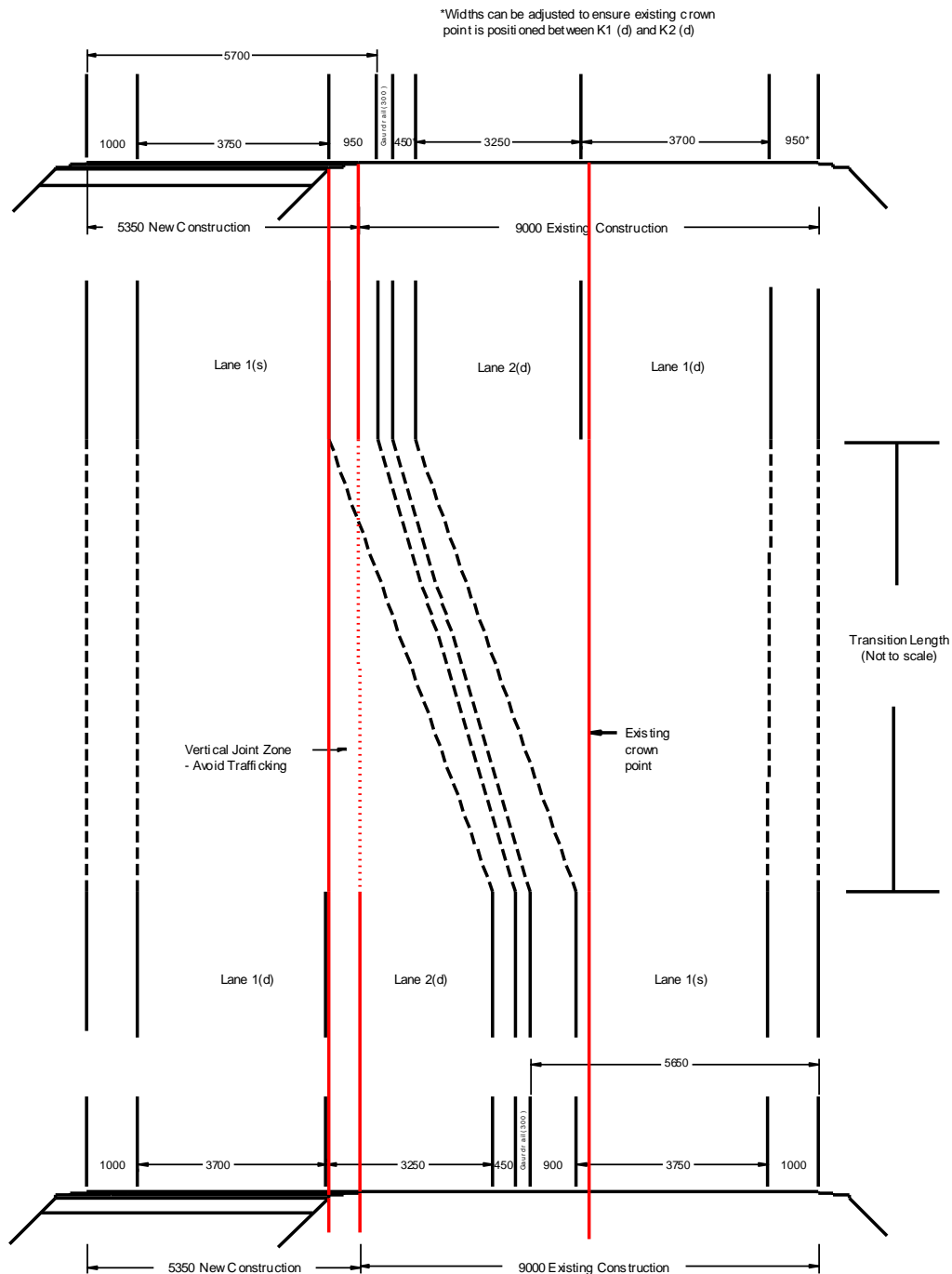


Figure 40. Option 4b – Combined single and double design.

The extent of degradation associated with trafficking of longitudinal vertical construction joints is unknown. Workmanship standards, bonding interaction between surfaces, and compaction levels will vary along the length of the joint. Accelerated degradation testing using a Heavy Vehicle Simulator (HVS) may provide useful information on this problem.

## 11.5. Reductions in recommended design widths

Amendments to standard designs are often required to overcome specific engineering difficulties. In other cases, amendments may be motivated by financial reasons. Amendments may include the replacement of 2+1 sections with 1+1 sections. They may also include width reductions in the cross-section design. Deviations from recommended design widths will influence vehicle position and amount of lateral wander. If these effects reduce the amount of lateral wander, degradation rates are likely to accelerate.

For conventional road design, the following diagram (for light vehicles) shows that decreases in lane width reduce the standard deviation value. It is possible that this trend will also apply to the single lane and double lane sections in a barrier separated road.

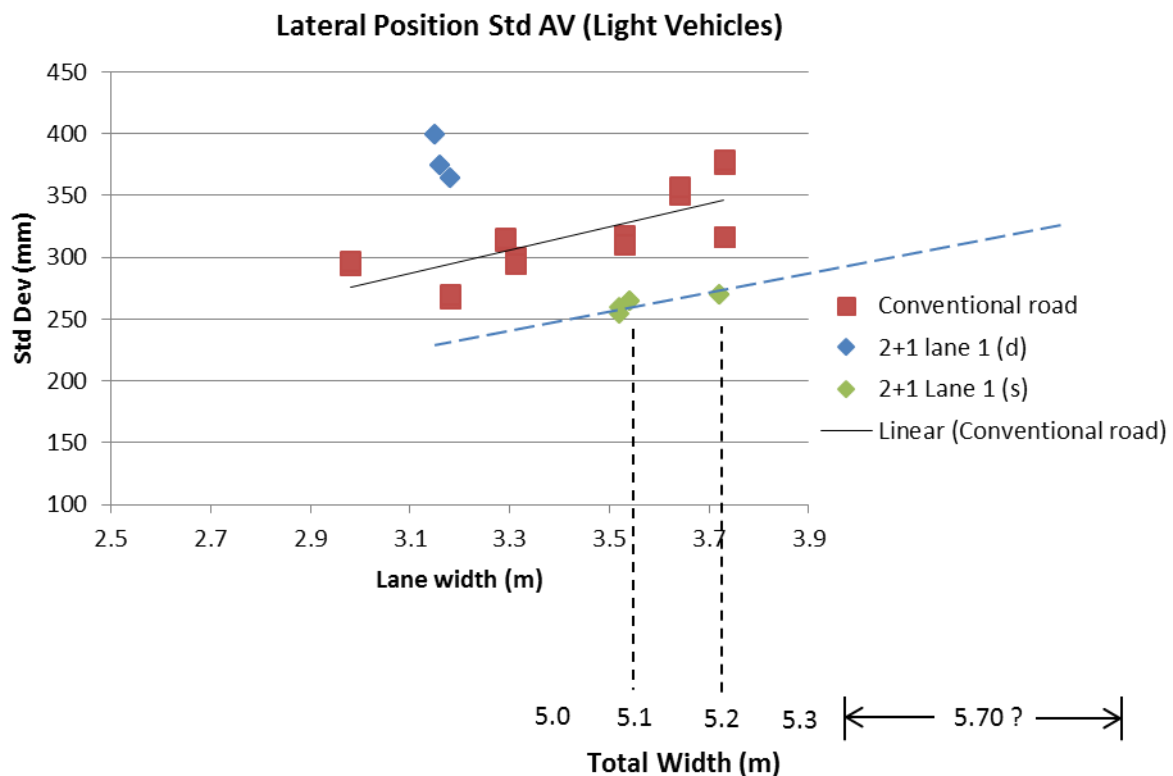


Figure 41. Average position standard deviations (refer to Chapter 6).

However, with barrier separated road design, lane width is not the only confining factor. The total width, between road edge and central barrier, also influences vehicle position and the amount of lateral wander. Total width, for single lane sections, can vary between 4.75 m and 5.00 m for conversions of existing 13 m wide roads. Total widths for widened or new constructions are recommended to be 5.50 m or 5.70 m.

The values for lane 1(s) in the above figure are associated with total widths between 5.10 m and 5.20 m. If a recommended width of 5.70 m had been constructed, standard deviation values would possibly have increased to around 300 mm. This extra deviation will increase lateral wander and reduce surface wear and deformation. This design width is possible and is detailed in figure 40.

## 11.6. Conclusion

The main problems associated with barrier separated road type design are:

- Increased confinement of traffic in the single lane sections
- Longitudinal vertical joints positioned under the offside wheel tracks

An ideal barrier separated road design should provide sufficient lane and verge widths to minimise traffic confinement in the single lane sections. The design should also ensure that vertical joints, between the new construction and existing structure, are positioned out with vehicle wheel tracks.

A single lane section width of 5.70 m will help reduce the effects of traffic confinement and will ensure that vertical joints are placed out with vehicle wheel tracks.

Placement of longitudinal vertical joints, between lanes 1 and 2, in the double lane section will never be ideal. It is impossible to eliminate trafficking over these joints. Consideration should, however, be given to a wider 3.70 m lane in lane one of the double lane section.

The design should also take into consideration the longitudinal alignment, especially at transition points between single and double lane sections. Weak “triangular” shaped tie in sections should be avoided where possible.

It is very difficult to produce a standard cross or long section design that will meet all requirements. For example:

- Asymmetrical design provides the best longitudinal design but will require a longitudinal vertical joint in lane two of the double lane section.
- Widening for the single lane sections will provide the best solution for reduced confinement and longitudinal vertical joint placement but will require “triangular” shaped tie in sections. Vehicles driving in lane 1 will also require to manoeuvre either right or left at each transition point.
- If no overlay of the existing surface is planned, then widening for the double lane section will provide the easiest solution. However, this design will also require “triangular” shaped tie in sections. Vehicles driving in lane 1 will also require to manoeuvre either right or left at each transition point.

In all cases, the interface between new and existing construction should be used as the start point for design. Consideration should also be given to vehicle types, position in the road, and amount of lateral wander in order to reduce the number of vehicles driving over longitudinal construction joints. If longitudinal joints can be placed out-with two standard deviations of a vehicles average position, only 2.5% of the vehicles will be driven over the joint. A 14.35 m cross section width may prove to be ideal.

## 12. Update of VTI Surface Wear Model

Using VTIs surface wear prediction model (Wågberg och Jacobson, 2007) it is possible to estimate surface wear in the single and double lane sections of barrier separated roads.

A similar version of the model is used in PMS Objekt, the Swedish Road Administrations pavement management system.

The following standard deviations are currently used in the surface wear model to describe the variation of average lateral position.

*Table 7. Standard deviations according to surface wear model.*

Type	Road width (m)	Lateral Position Std Dev (mm)
1	7	250
2	9	300
3	13	450
4	Wide Road	500
5	Motor Way	250
6	Tunnels	225
7	2+1 Road	200
8	Narrow Road	180

For barrier separated roads, it is recommended that Road type 7 is used in calculations for double lane sections – Lane 1(d) and Lane 2(d). Road type 6 is recommended for single lane sections – Lane 1(s).

However, actual measured standard deviations of vehicle lateral position do not match these values. With reference to the following table from chapter 6, vehicles in the double lane section, Lane 1(d), have a deviation value of 365. The deviation value for vehicles in the single lane section, Lane 1(s) is 265.

*Table 8. Actual standard deviations according to survey data.*

Lane	Lane Width (m)	Lateral Position Std Dev (mm)	
		Light vehicle	Commercial Vehicle
Lane 1 (s)	3.75	265	270
Lane 1 (d)	3.15	365	230

Using the actual standard deviation values will reduce the amount of estimated surface wear by around 25% in the single lane section and by approximately 40% in the double lane section.

This suggests that lateral position standard deviation recommendations in the surface wear model, associated with barrier separated 2+1 roads, are inaccurate and should be updated.



## 13. Recommendations and further research

### 13.1. Design – Conversion of 9 meter road to 2+1

It has been shown that rutting develops quicker in the single lane sections of barrier separated roads. The rutting rate in the double lane sections was comparable with conventional design. It was also confirmed that confinement of vehicles was more severe in the single lane sections. Increasing the total width of the single lane section is possible but this will result in a higher initial investment cost. If an existing road is widened to accommodate the new single lane section (Figure 42), a total single lane width of 5.70 m can be achieved if the total road width is extended to 14.35 m.

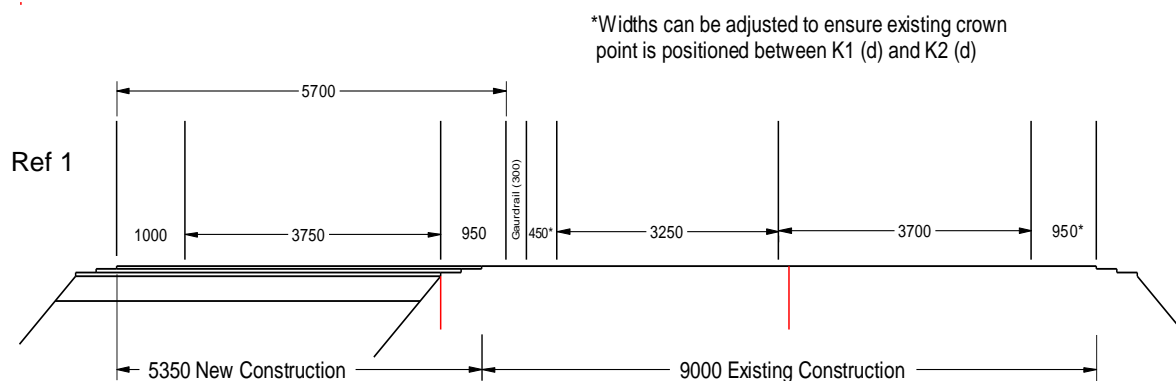


Figure 42. Widening for single lane section.

However, when the road structure is widened to accommodate the new lane in the double lane section, a maximum width of only 5.30 m is possible for the single lane section (Figure 43).

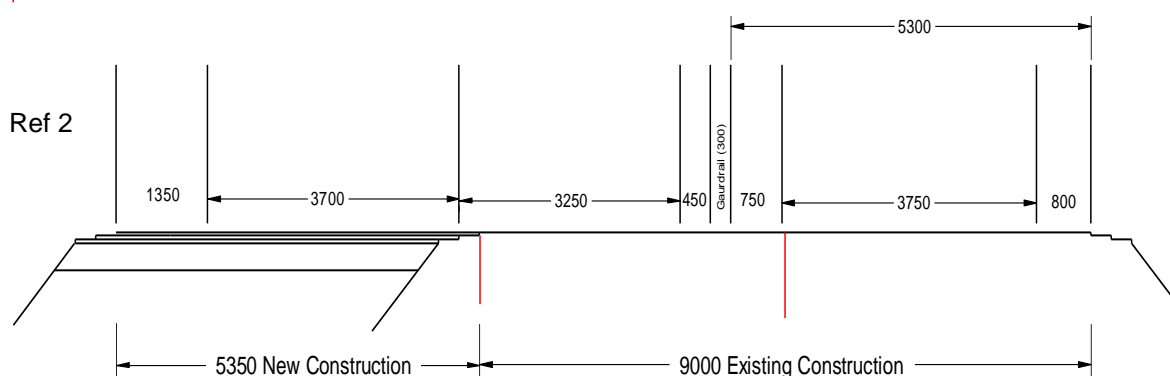


Figure 43. Widening for double lane section.

If the vertical joints between new and existing construction are placed further into lane 2 of the double lane section (Figure 44), then the total width in the single lane section can be increased from 5.30 m to 5.65 m.

The joints will be subjected to direct trafficking, but, as most vehicles in lane 2 are likely to be light vehicles, this may be an acceptable compromise.

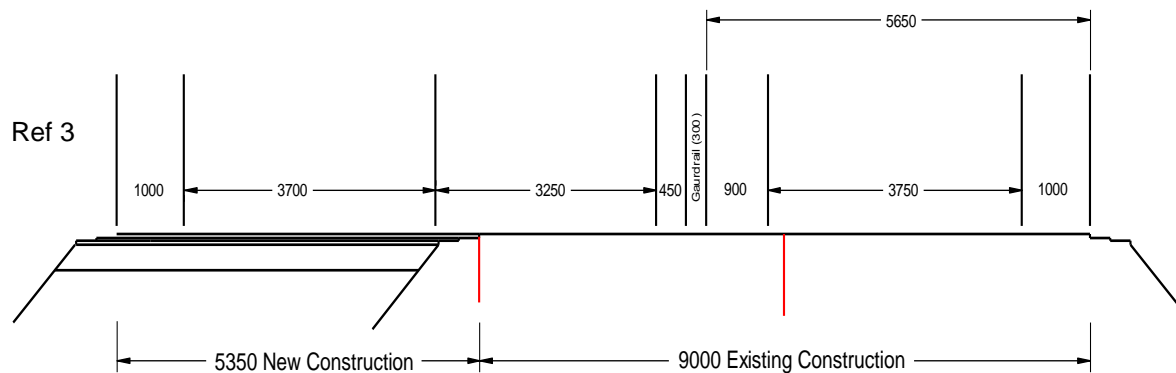


Figure 44. Widening for double lane section.

This additional width should reduce the confinement effect and therefore reduce the rate of rutting.

### 13.2. Design – New build 2+1

New build projects should include a minimum cross section width of 14.40 m. This allows for a 3.70 m wide lane to be constructed in lane 1 of the double lane section. This extra width will help to confine vehicle wander within lane and edge markings. The 5.70 m total width in the single lane section should also increase vehicle lateral wander to more acceptable levels.

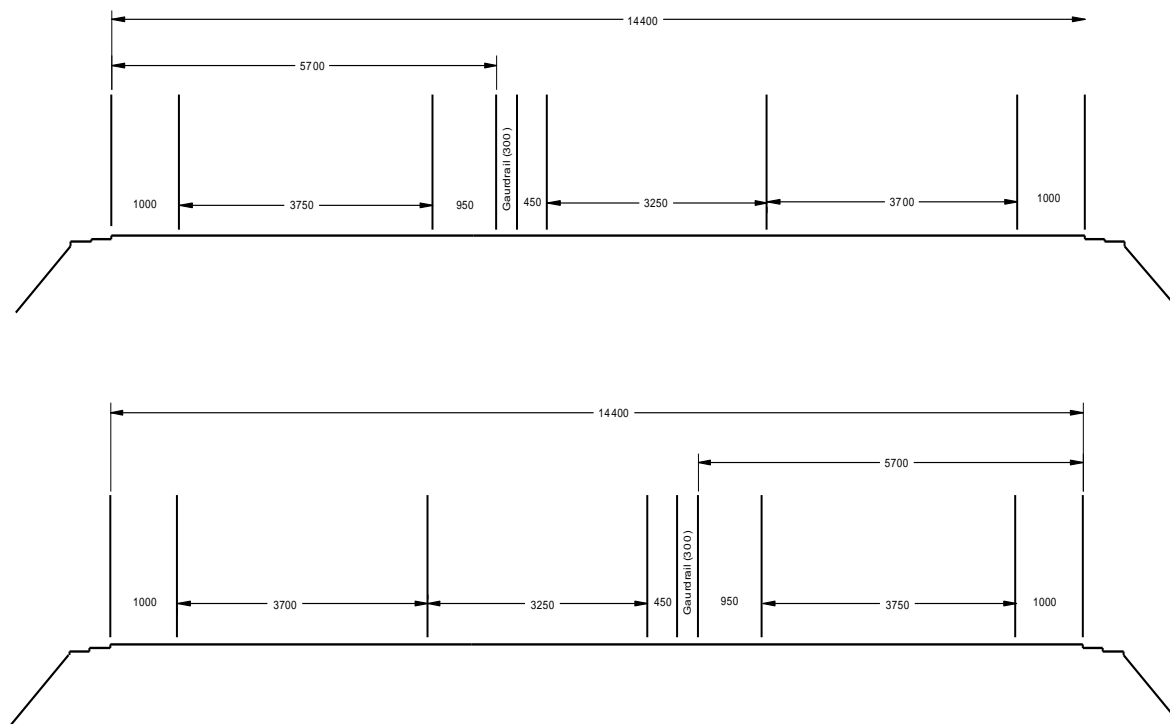


Figure 45. New build design options with single lane on left side (top) and single lane on right (bottom).

### 13.3. Design - Road 22, Söderköping to Valdemarsvik

The design used for this road section should also be given consideration. A wide side verge is provided along most of the single lane sections.

Comparisons of rut depth values showed that development rates are very similar in both single and double lane sections. This could indicate that lateral wander of vehicles is consistent along the length of the road - single and double lane sections, and that no accelerated degradation is taking place.

However, this design may only be suitable for new builds. Applying this type of design to a conversion of a 9 m wide road type would result in longitudinal vertical joints being placed in the wheel tracks of lane 2 in the double lane section.

#### **13.4. Conversion of 9 meter wide road to 1+1 barrier separated road**

Converting an existing 9 m wide road to a 1+1 barrier separated road, without additional widening, resulted in extreme confinement of vehicular traffic. Survey data showed lateral wander reductions of 44% for light vehicles and 39% for commercial vehicles.

In many cases this type of conversion is likely to be the most economical in terms of initial investment; however, very careful consideration must be given to the maintenance cost implications produced by higher surface wear and deformation rates.

Follow up studies on this type of design are recommended to determine how extreme degradation levels are.

#### **13.5. Vertical construction joints**

When possible, vertical construction joints should be placed out with vehicle wheel tracks. It is advisable that the position of the vertical joints between new and existing construction should be used as the start point of any design.

To accommodate this recommendation, amendments to certain standard designs in VGU will be required. In addition, the extent of degradation associated with trafficking of longitudinal vertical construction joints is unknown. Workmanship standards, bonding interaction between vertical surfaces, and compaction levels will vary along the length of the joint. Accelerated degradation testing using a Heavy Vehicle Simulator (HVS) may provide useful information on this problem.

#### **13.6. VTI Surface wear model**

Current lateral position standard deviations, used in the VTI surface wear model, are not accurate and should be updated.

Using data from the position surveys carried out in this project, the value used for the single lane section should be increased from 225 mm to 265 mm. The double lane section value should also be changed from 200 mm to 365 mm.

The Swedish Road Administrations pavement management system, PMS Objekt, includes a module that is a variation of the surface wear model. This may also require updating.

#### **13.7. Construction standards**

Differences in surface wear and deformation rates could also be evened out by varying construction standards.

For example, to reduce surface wear, better quality surface course aggregate could be specified for use in the single lane sections. Resistance against deformation could also be achieved by specifying additional, thicker or stiffer construction layers. An alternative would be to use polymer modified bitumen (PMB) or polymer modified asphalt (PMA).

However, introducing different design standards on the same section of road could prove to be impractical, especially if an existing road structure is being converted into a barrier separated road.



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Håkan Jansson, Trafikverket, NVF Seminarium 2011, Smala körfält - en utmaning för beläggningsbranschen

Carl-Gösta Enocksson, Trafikverket, NVF Seminarium 2011, Smala körfält - en utmaning för beläggningsbranschen



## Appendix 1

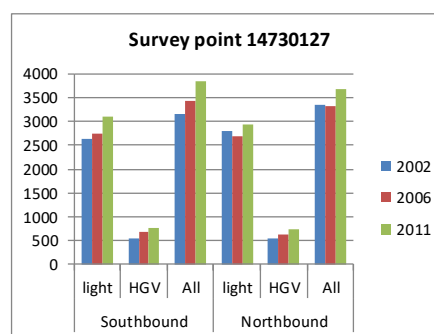
### E4 Traffic Flow Volume (AADF)



Figure 46. Summary of Traffic Volume Data from Three Survey Points.

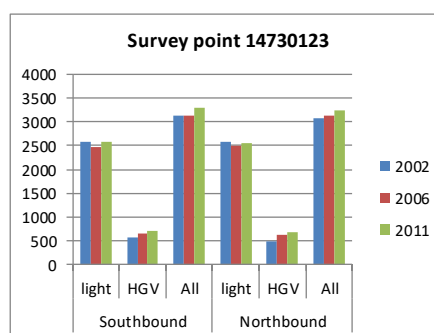
#### 14730127

Year	Southbound			Northbound		
	light	HGV	All	light	HGV	All
2002	2630	540	3170	2810	540	3350
2006	2740	690	3430	2690	620	3310
2011	3090	760	3850	2940	750	3690



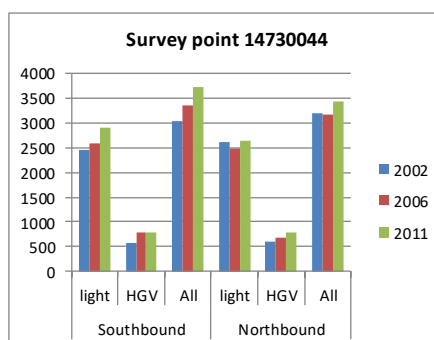
#### 14730123

Year	Southbound			Northbound		
	light	HGV	All	light	HGV	All
2002	2570	560	3130	2580	490	3070
2006	2480	650	3130	2490	630	3120
2011	2590	710	3300	2560	690	3250



#### 14730044

Year	Southbound			Northbound		
	light	HGV	All	light	HGV	All
2002	2440	590	3030	2600	600	3200
2006	2580	780	3360	2490	670	3160
2011	2910	800	3710	2630	790	3420







## Appendix 2

### E12 Traffic Flow Volumes (AADF)

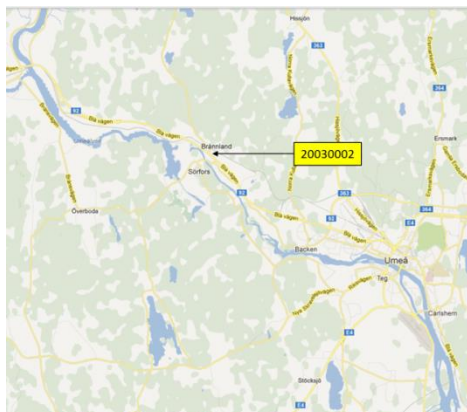
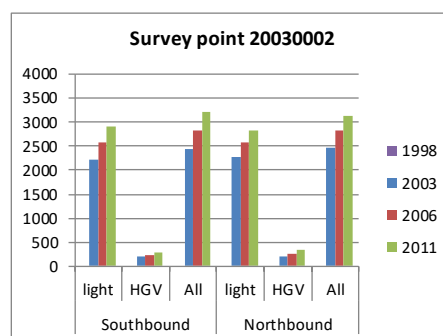


Figure 47. Summary of Traffic Volume Data from One Survey Point, reference 20030002.

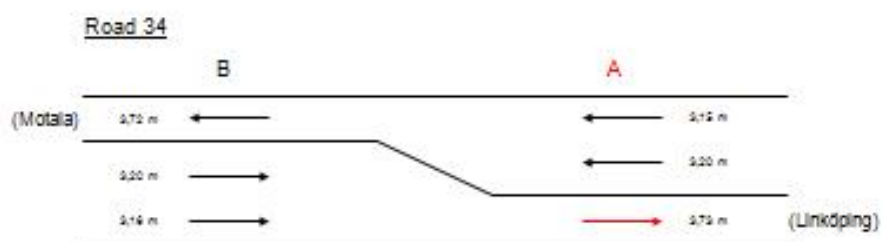
20030002						
Year	Southbound			Northbound		
	light	HGV	All	light	HGV	All
2003	2230	210	2440	2270	200	2470
2006	2580	240	2820	2580	250	2830
2011	2920	280	3200	2810	330	3140





## Appendix 3

### Position in Road - Road 34 A1



4 survey points: A1, A2, B1 och B2



'Z' Survey (A1) – 34 (North of Linköping)

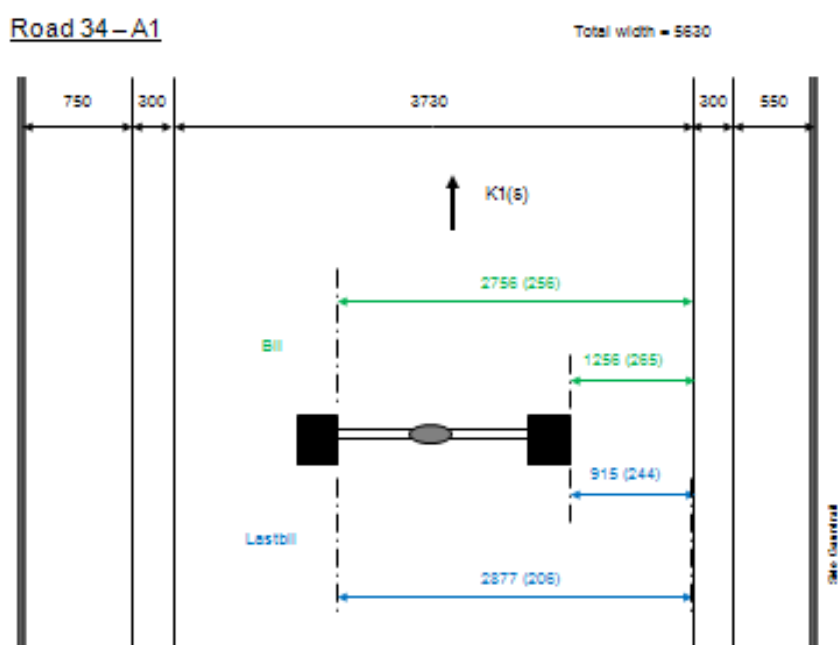
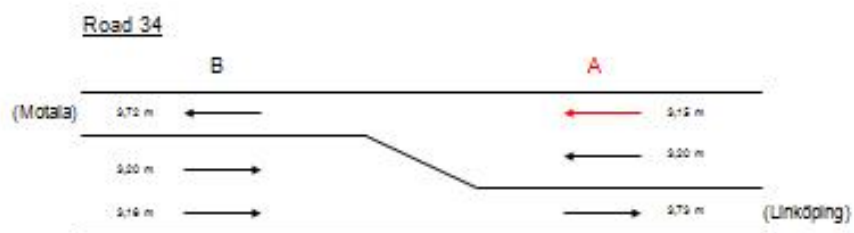


Figure 48. Position in Road – Road 34 A1.

Figure

## Position in Road - Road 34 A2



4 survey points: A1, A2, B1 and B2



'Z' survey (A2) – 34 (North of Linköping)

## Road 34 – A2

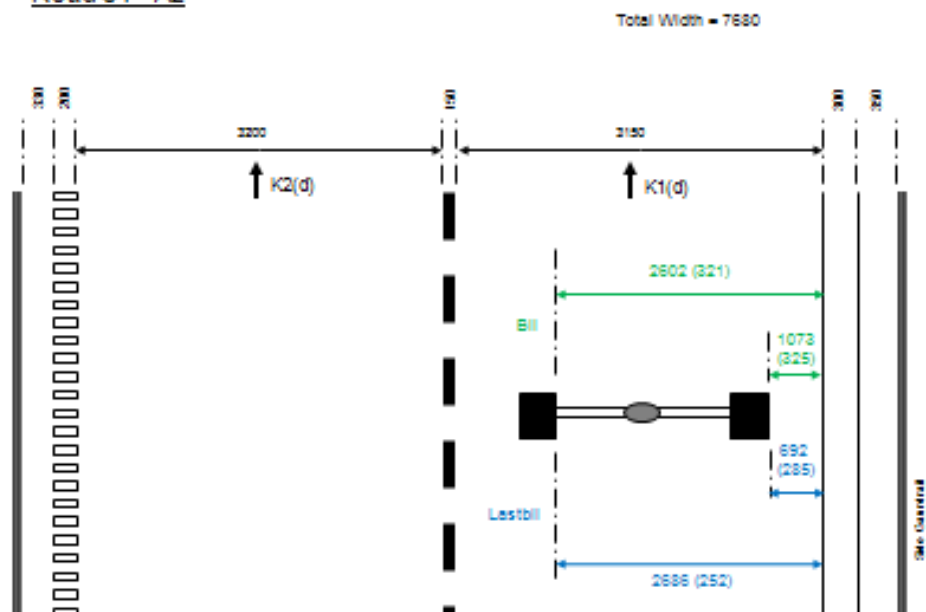
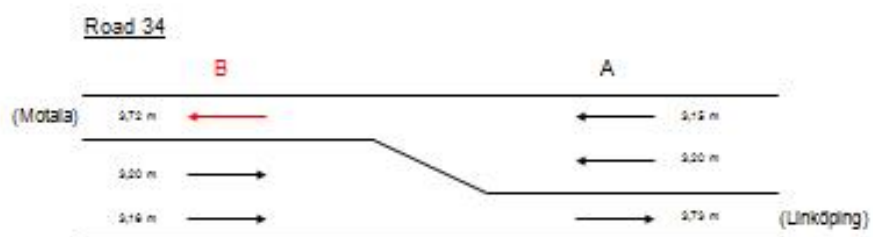


Figure 49. Position in Road – Road 34 A2.

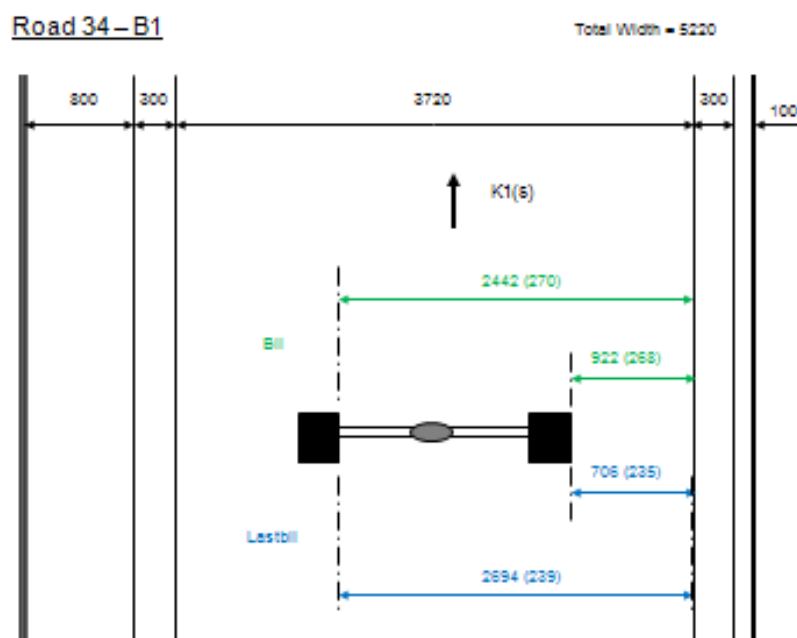
## Position in Road - Road 34 B1



4 survey points: A1, A2, B1 och B2



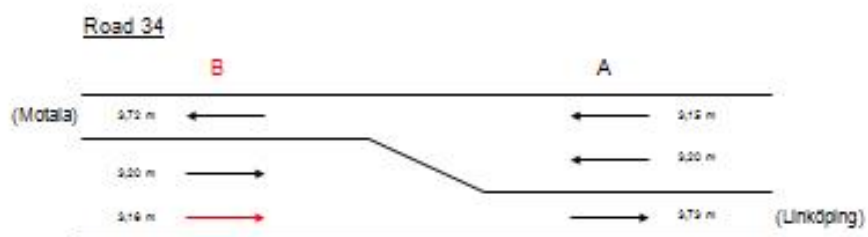
"Z" survey (B1) – 34 (North of Linköping)



50. Position in Road – Road 34 B1.

Figure

## Position in Road - Road 34 B2



4 survey points: A1, A2, B1 och B2



"Z" survey (B2) – 34 (North of Linköping)

## Road 34–B2

Total Width = 7880

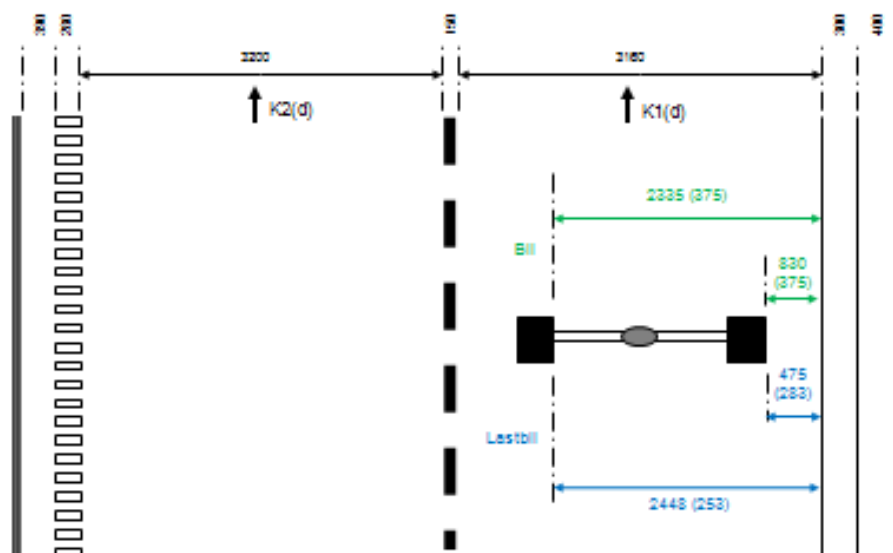
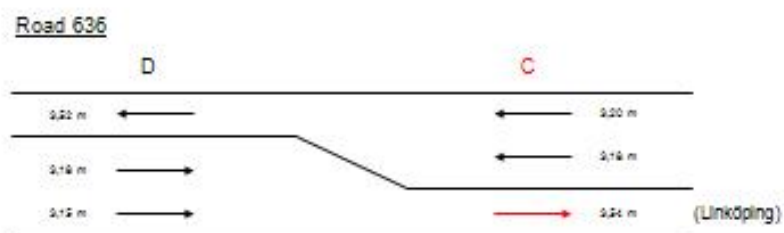


Figure 51. Position in Road – Road 34 B2.

## Position in Road - Road 636 C1



4 survey points: C1, C2, D1 and D2



'Z' survey (C1) – 636 (South West of Linköping)

## Road 636 – C1

Total Width = 5130

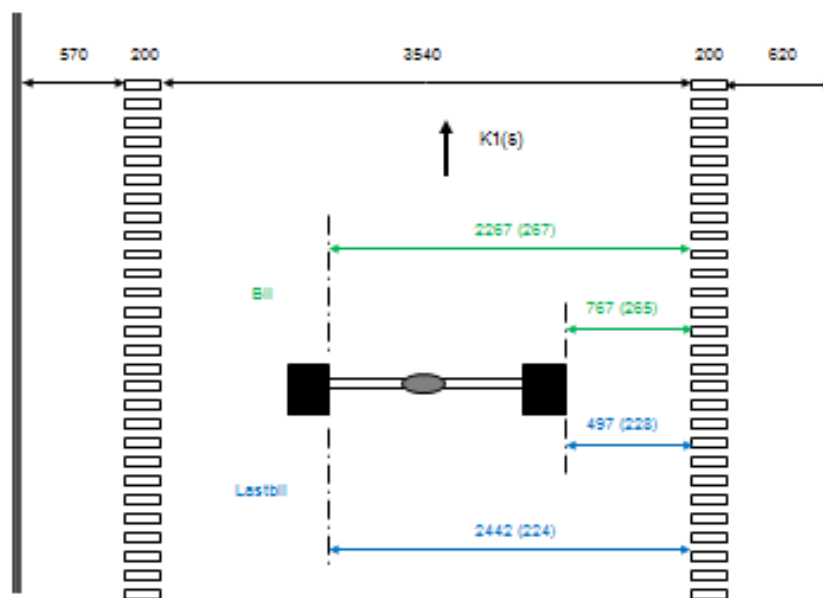
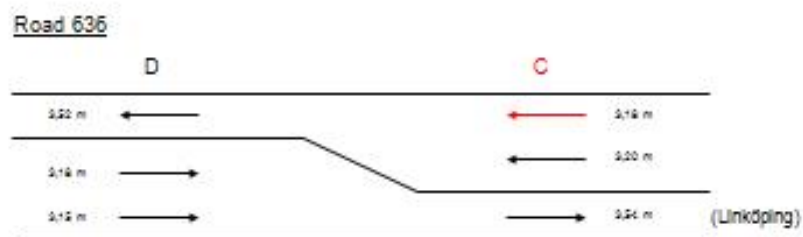


Figure 52. Position in Road – Road 636 C1.

## Position in Road - Road 636 C2



4 survey points: C1, C2, D1 and D2



"Z" survey (C2) – 636 (South West of Linköping)

## Road 636 – C2

Total Width = 7890

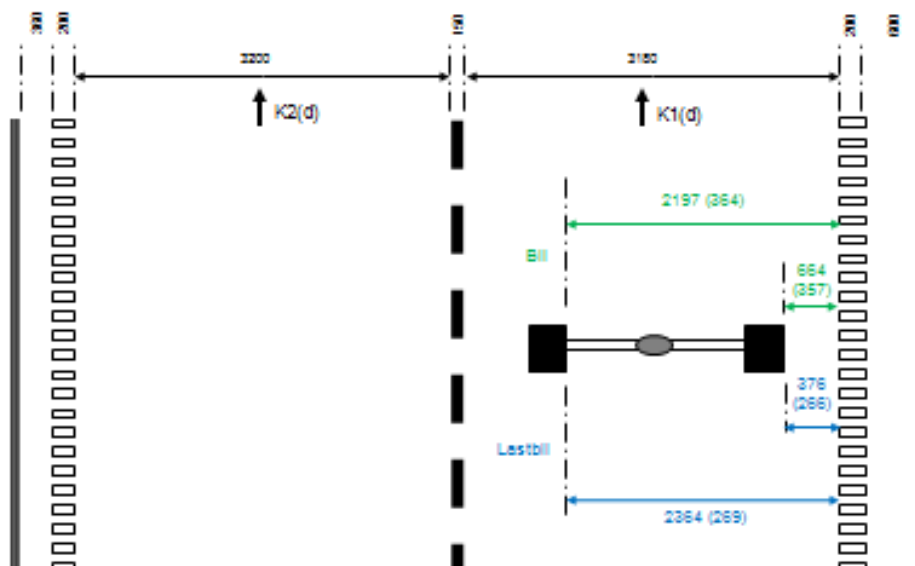
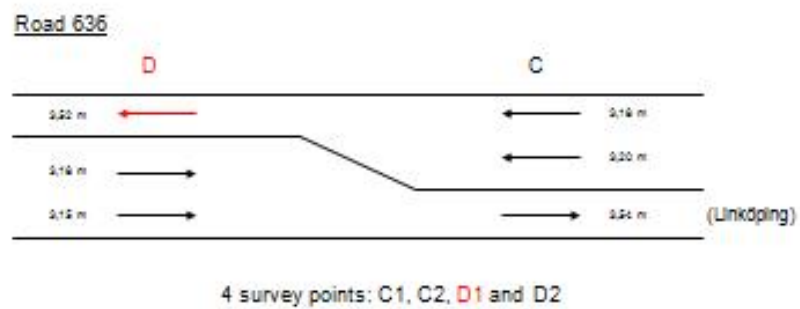


Figure 53. Position in Road – Road 636 C2.



## Position in Road - Road 636 D1



'Z' survey (D1) – 636 (South West of Linköping)

## Road 636 – D1

Total Width = 5170

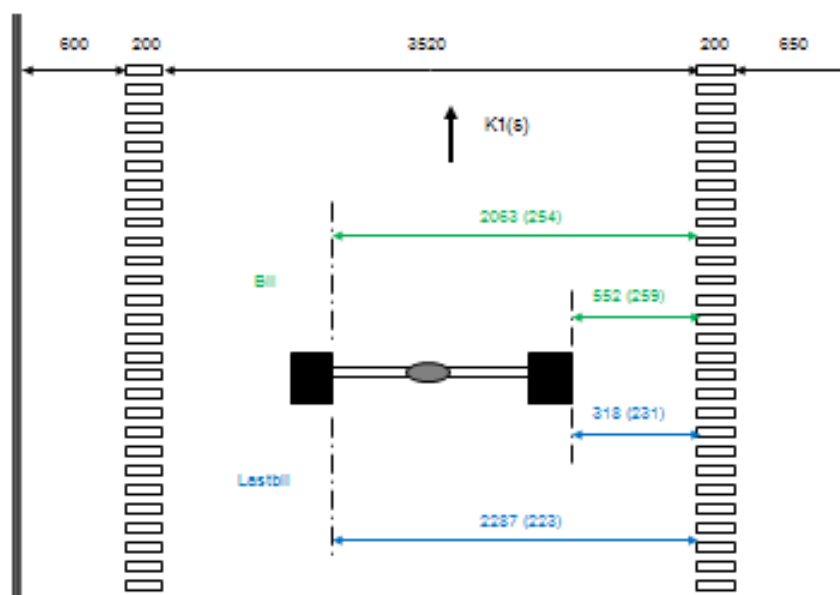
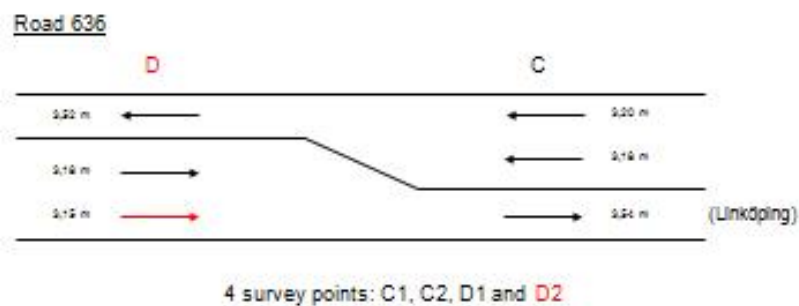


Figure 54. Position in Road – Road 636 D1.

## Position in Road - Road 636 D2



"Z" survey (D2) – 636 (South West of Linköping)

## Road 636 – D2

Total Width = 7780

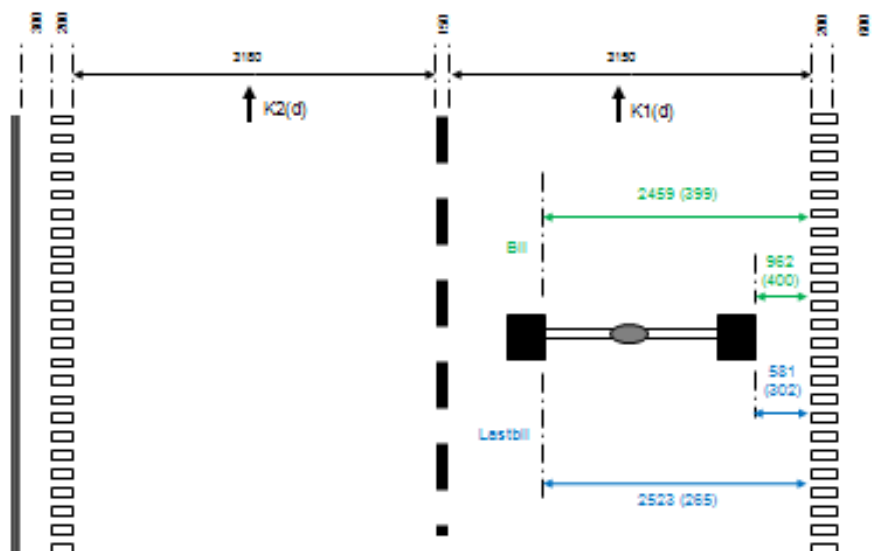


Figure 55. Position in Road – Road 636 D2.

## Appendix 4

### Östergötland and Skåne Position Surveys

Table 9. Conventional Road Type – Average Position Standard Deviations (LV).

<u>Personbil</u>				
		Std Av (mm)		Medel Hastighet
Väg	Mät Plats	Vänster	Höger	(km/h)
9/11	Skåne 3B	380	380	76,6
19	Skåne 3A	350	360	92,7
Bergsvägen	Östergötland 3B	320	320	88,4
34	Östergötland 3A	320	310	93,3
19	Skåne 1C	310	320	92,3
34	Östergötland 1C	300	300	88,9
19	Skåne 1B	300	300	90,2
135	Östergötland 1A	270	270	87,8
19 (sidräcke)	Skåne 4A	350	340	88,6
34 (sidräcke)	Östergötland 4A	330	320	93,4
32 (sidräcke)	Östergötland 4B	320	320	90
9/11 (sidräcke)	Skåne 4B	310	310	88
135 (sidräcke)	Östergötland 2B	250	250	91,2
135 (sidräcke)	Östergötland 2A	240	240	91,2
19 (sidräcke)	Skåne 2B	320	310	93,1
19 (sidräcke)	Skåne 2A	300	300	92,2

Table 10. Conventional Road Type – Average Position Standard Deviations (HGV).

<u>Lastbil</u>				
		Std Av (mm)		Medel Hastighet
Väg	Mät Plats	Vänster	Höger	(km/h)
9/11	Skåne 3B	330	350	69,8
Bergsvägen	Östergötland 3B	310	280	83,9
135	Östergötland 1A	280	270	79,8
19	Skåne 3A	260	290	85,5
34	Östergötland 3A	250	240	85,8
19	Skåne 1C	230	230	84,4
34	Östergötland 1C	230	250	84,5
19	Skåne 1B	220	240	81,9
19 (sidräcke)	Skåne 4A	290	310	85
9/11 (sidräcke)	Skåne 4B	260	270	84,9
32 (sidräcke)	Östergötland 4B	240	270	83,7
34 (sidräcke)	Östergötland 4A	240	260	84,8
135 (sidräcke)	Östergötland 2A	250	250	83,8
135 (sidräcke)	Östergötland 2B	180	220	83,7
19 (sidräcke)	Skåne 2A	220	250	85,7
19 (sidräcke)	Skåne 2B	210	240	88,9



## Appendix 5

### E6 Uddevalla Position Survey (McGarvey, 2016)

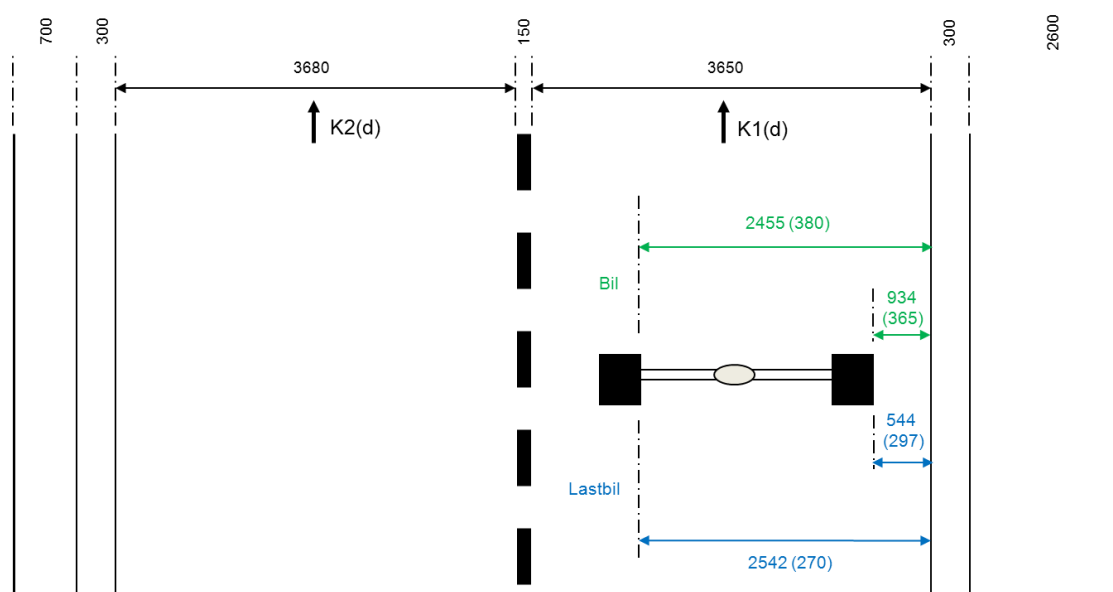


Figure 56. E6 (Motorway Road Type) – Average Position and Standard Deviations.



Figure 57. E6 (motorway) Position Survey.



## Appendix 6

### Road 34 (1+1 road type) Position Survey (McGarvey, 2016)

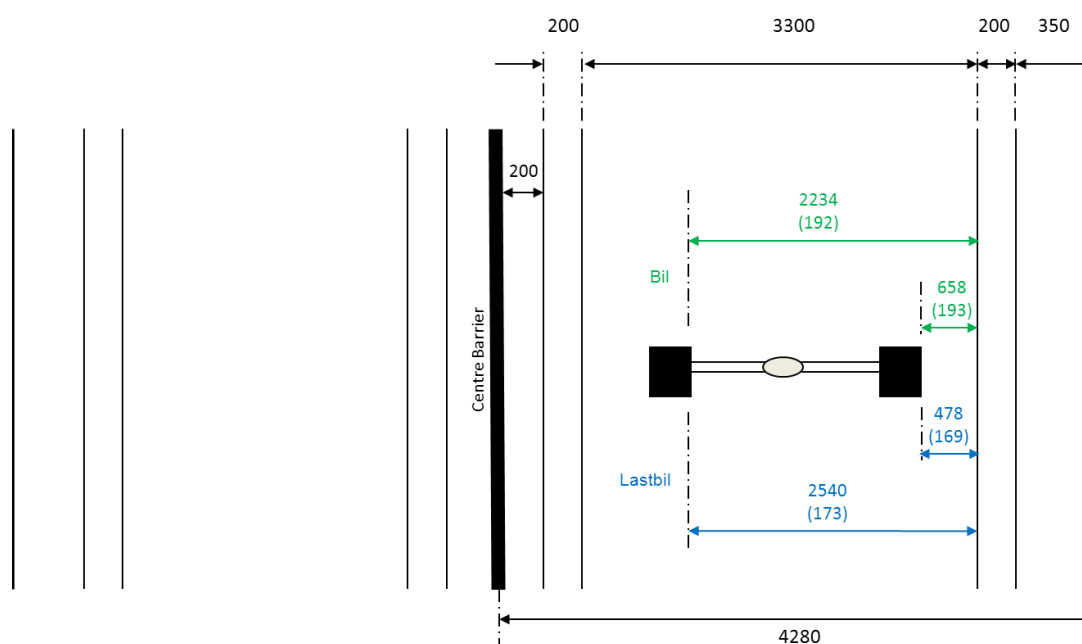


Figure 58. Road 34 (1+1 Road Type) – Average Position and Standard Deviations.



Figure 59. Road 34 (1+1) Position Survey.





## Appendix 7

### Surface Wear – Kulkvarnsvärde 7 and 10

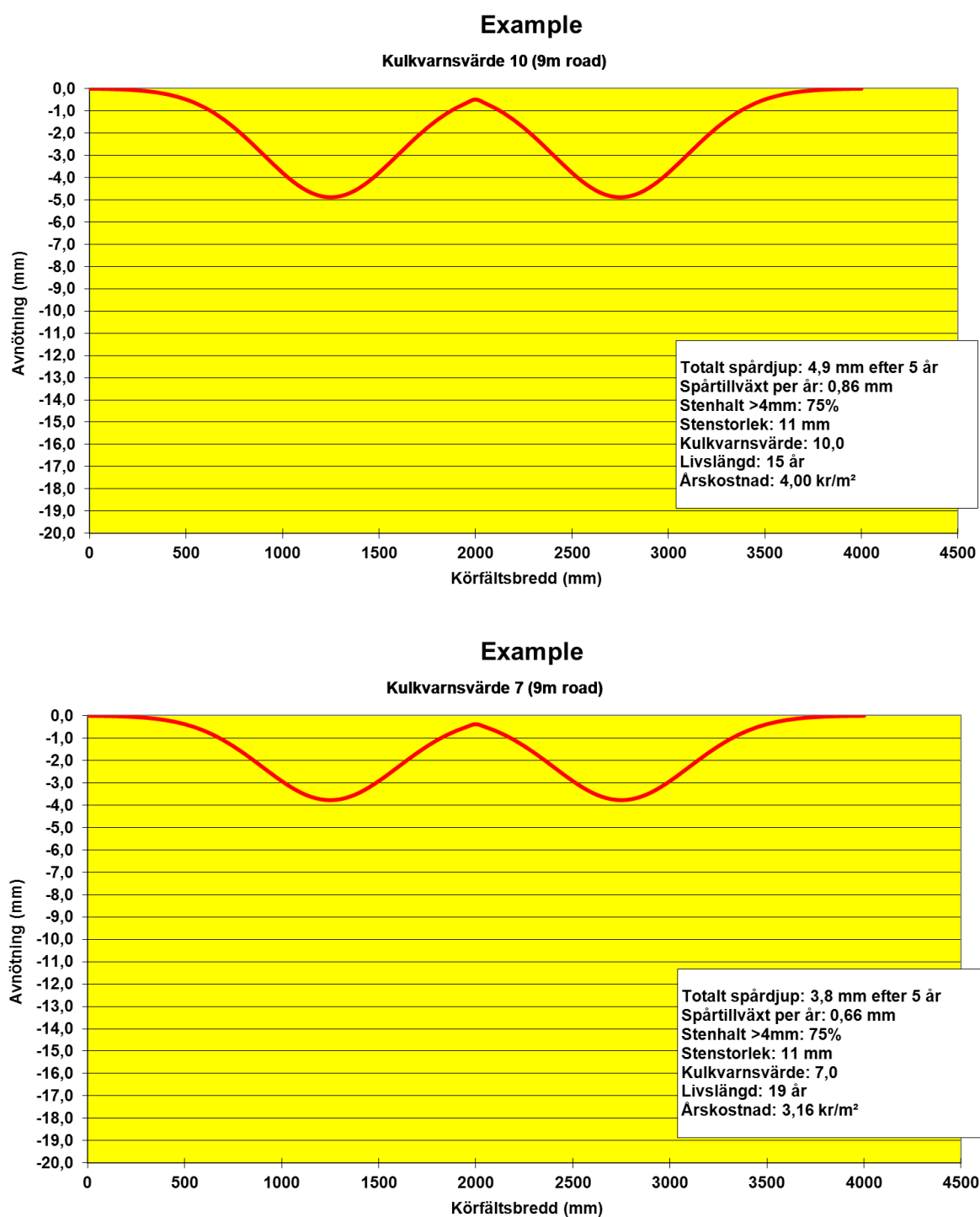


Figure 60. Surface Wear Comparisons – Kulkvarnsvärde 7(bottom) and 10 (top).

Surface wear per year:

0.66 mm (kulkvarnsvärde 7) increasing to 0.86 mm (kulkvarnsvärde 10) = 30% increase



## Appendix 8

### Vehicle Distribution Pattern

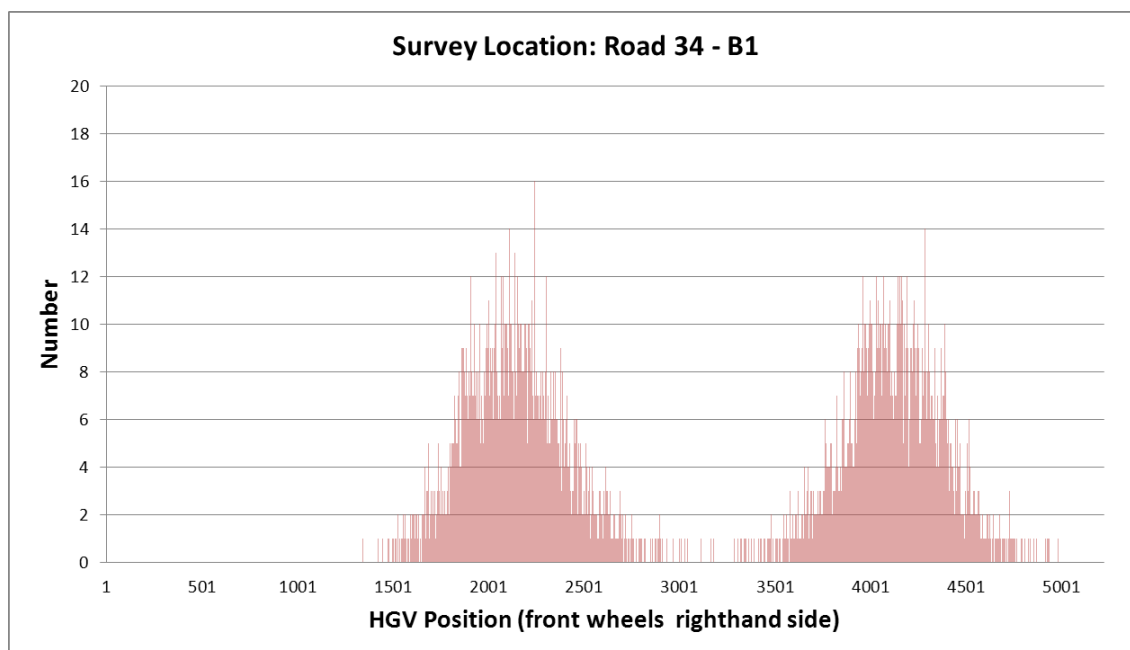


Figure 61. Road 34 (2+1 road type) – HGV Position Distribution.

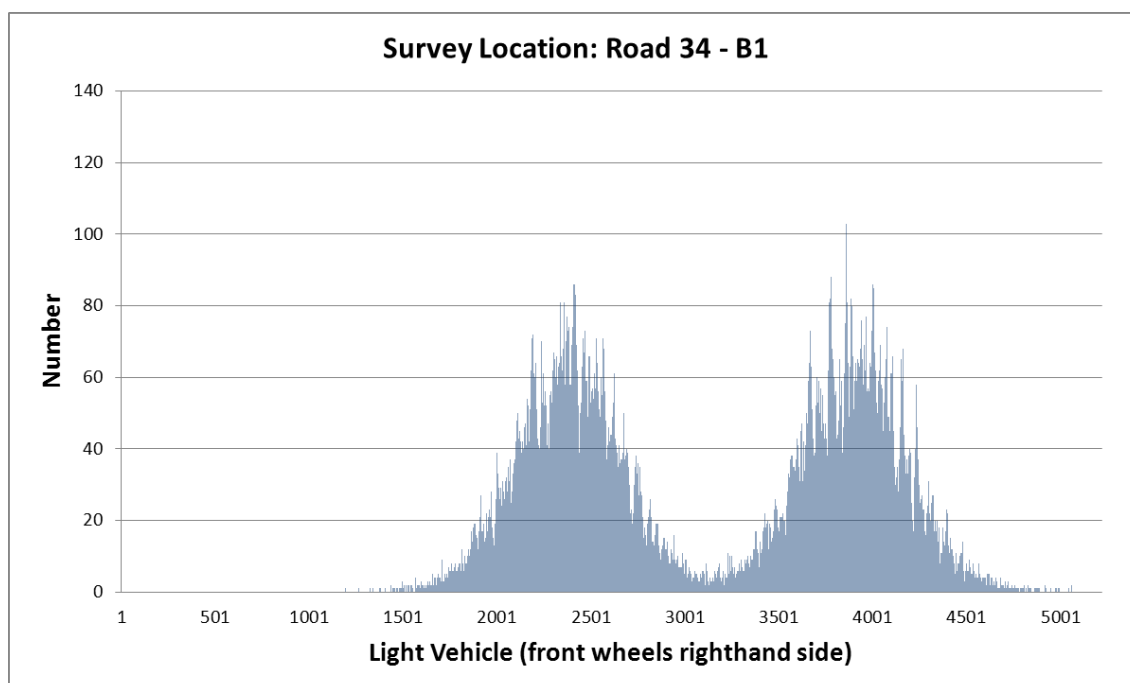


Figure 62. Road 34 (2+1 road type) – LV Position Distribution.

The above examples show that distribution patterns look quite symmetrical and have a distinctive bell shape with a single peak. This is consistent with normal distribution.

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