



Vehicle lateral position depending on road type and lane width

Vehicle position surveys carried out on the Swedish road network

Terence McGarvey

VTI rapport 892A

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Abstract

In previous studies it was found that vehicle lane position varied depending on road type and lane width. These variations will have a direct effect on the rate of surface wear and will influence where stresses and strains are distributed in the pavement structure.

In order to quantify these variations, a series of position surveys were carried out on common road types found on the Swedish road network. Twenty-one sets of data provided information on over 271,000 vehicles.

It was possible to split vehicles into three categories and calculate average positions and standard deviations. Values were then used to describe the distribution of lateral position (wheel path), average position, and variation of lateral position (lateral wander).

Factors such as lane type, lane width, verge width, total width, and close proximity of guardrail all had some influence on vehicle position and amount of lateral wander. The extent of lateral wander varied quite considerably. Values associated with light vehicles varied between 455 millimetres and 190 millimetres. Commercial traffic values were lower and ranged between 430 millimetres and 140 millimetres.

These large variations will have a significant effect on road degradation rates and should be taken into account when planning construction or maintenance work.

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I tidigare studier om mötesfria vägar har det rapporterats att ett fordon's sidolägesfördelning varierar beroende på vägtyp och filbredd. Variationer i ett fordon's sidoläge har en direkt effekt på vägyteslitage och påverkar hur spänningar och töjningar fördelas i överbyggnadsstrukturen.

För att fastställa omfattningen av dessa variationer har en rad undersökningar på sidolägen utförts på vanligt förekommande vägtyper i det svenska vägnätet. Information om mer än 271 000 fordon utvanns ur tjugoen datauppsättningar.

Undersökningsdatan gjorde det möjligt att dela upp fordon i tre grupper, beräkna sidoläge medelvärde och standardavvikelse samt sammanfatta sidolägesfördelning, genomsnittligt sidoläge och sidolägesvariation.

Faktorer som körfältstyp, körfältsbredd, vägrensbredd, total bredd och avstånd till skyddsräcke påverkade alla sidoläge och sidoförflyttning. Omfattningen av sidoförflyttning varierade väsentligt. Värden för lätta motorfordon varierade mellan 190 millimeter och 455 millimeter. Värdena för tung trafik var lägre och varierade mellan 140 millimeter och 430 millimeter.

Detta är stora variationer som kommer att ha en betydande effekt på vägars nedbrytningstakt. De bör därför tas med i beräkningen vid planering av konstruktions- eller underhållsarbete.

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Foreword

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Linköping, June 2016

Terence McGarvey
Project leader

Quality review

Internal peer review was performed on 10 February 2016 by Leif Sjögren. Terence McGarvey has made alterations to the final manuscript of the report. The research director Anita Ihs examined and approved the report for publication on 30 May 2016. The conclusions and recommendations expressed are the author's/authors' and do not necessarily reflect VTI's opinion as an authority.

Kvalitetsgranskning

Intern peer review har genomförts 10 februari 2016 av Leif Sjögren. Terence McGarvey har genomfört justeringar av slutligt rapportmanus. Forskningschef Anita Ihs har därefter granskat och godkänt publikationen för publicering 30 maj 2016. De slutsatser och rekommendationer som uttrycks är författarens/författarnas egna och speglar inte nödvändigtvis myndigheten VTI:s uppfattning.

Contents

Summary	9
Sammanfattning	11
1. Introduction	13
2. Aim	14
3. Method	15
3.1. Measurement technique	16
3.2. Distribution of lateral position (right hand side of front wheels).....	17
3.3. Average position and standard deviations.....	18
3.4. Vehicle tracking	19
3.5. Position survey locations	20
4. Results and discussion.....	22
4.1. Standard deviations of average position	23
4.2. 2+1 road type	24
4.3. Conventional road converted to “1+1” barrier separated road.....	25
4.4. Double lane sections	26
4.5. Effect of lane type and side verge widths	27
4.6. Narrow lane and side verge widths	28
4.7. Lateral wander and lane widths.....	29
4.8. Rut development rates.....	30
5. Conclusions and further work	31
References	33
Appendix 1	35
Appendix 2	37

Summary

Vehicle lateral position depending on road type and lane width. Vehicle position surveys carried out on the Swedish road network

by Terence McGarvey (VTI)

In previous studies of barrier separated road types, it was found that vehicle lane position and the amount of lateral wander varied depending on road type and lane width.

Variations in vehicle lane position and the amount of lateral wander will have a direct effect on the rate of surface wear and will influence where stresses and strains are distributed in the pavement structure.

In order to determine the extent of these variations, a series of position surveys were carried out on common road types found on the Swedish road network:

- conventional (7.7 m wide to 9.4 m wide),
- motorway,
- barrier separated (2+1),
- barrier separated (1+1),
- four lanes, and
- conventional (13 m with wide side verge).

Twenty-one sets of survey data provided information on over 271,000 vehicles. The data was divided into three groups depending on approximate axle track width:

- light vehicles (1.5 m track width),
- heavy goods vehicle 1 (1.8 m track width), and
- heavy goods vehicle 2 (2.1 m track width).

Using the survey data, it was possible to calculate and plot the distribution of lateral position (also called wheel path), the average position, and the variation of lateral position (also called lateral wander) for each group.

Factors such as lane type, lane width, verge width, total width, and close proximity of guardrail all had some influence on vehicle position and amount of lateral wander.

The extent of lateral wander varied quite considerably. Values associated with light vehicles varied between 455 millimetres and 190 millimetres. Commercial traffic values were lower and ranged between 430 millimetres and 140 millimetres.

These are large variations and will have a significant effect on road degradation rates. Such variations should be taken into account when planning construction or maintenance work.

Sammanfattning

Fordons variation i sidled beroende på vägtyp och körfältsbredd

av Terence McGarvey (VTI)

I tidigare studier om mötesfria vägar har det rapporterats att ett fordons sidoläge varierar beroende på vägtyp och körfältsbredd.

Variationer i ett fordons sidoläge har en direkt effekt på vägyteslitaget och påverkar hur spänningar och töjningar distribueras i överbyggnadsstrukturen.

För att fastställa omfattningen av dessa variationer har en rad sidolägesmätningar utförts på vanligt förekommande vägtyper i det svenska vägnätet:

- Traditionell väg (7,7 – 9,4 m bred)
- motorväg
- mötesfri väg (2+1)
- mötesfri väg (1+1)
- fyrfilig väg
- traditionell väg (13 m med bred vägren).

Information om mer än 271 000 fordon utvanns ur tjugoen datauppsättningar. Data delades in i tre grupper beroende på axelspårvidd:

- Lätta motorfordon (1,5 m spårvidd)
- tunga lastfordon 1 (1,8 m spårvidd)
- tunga lastfordon 2 (2,1 m spårvidd).

Insamlad data gjorde det möjligt att beräkna och kartlägga sidolägesfördelning, genomsnittligt sidoläge och variation i sidoläge för varje grupp.

Faktorer som körfältstyp, körfältsbredd, vägrensbredd, total bredd och avstånd till skyddsräcke påverkade alla sidoläge och sidoförflyttning.

Det var stora skillnader i sidolägesvariationen beroende på fordons- och vägtyp. Värdet för lätta motorfordon varierade mellan 190 millimeter och 455 millimeter. Värdena för tung trafik var lägre och varierade mellan 140 millimeter och 430 millimeter.

Detta är stora variationer som kommer att ha en betydande effekt på vägars nedbrytningstakt. De bör därför tas med i beräkningen vid planering av konstruktions- eller underhållsarbete.

1. Introduction

This report summarises a research project carried out on behalf of the Swedish Road Administration (Trafikverket).

In a recently finished but not yet published VTI Project (McGarvey, 2016), studies have revealed that vehicle position and confinement levels can vary depending on road type and lane width. For example, comparisons between conventional road types and barrier separated road types indicated that in the single lane section of a “2+1” barrier separated road, vehicle lateral wander reduced by 24% for light vehicles and 19% for commercial traffic. When compared to a “1+1” barrier separated road, the amount of lateral wander reduced by 44% for light vehicles and 39% for commercial traffic.

In VTI Report 636 (Carlsson, 2009), a series of rut depth measurements were taken on four different barrier separated road sections. The report shows that rut depth development rates were not consistent through the single and double lane sections. Although the rut development rates could have been influenced by differences in construction standards, it is also possible that the different road types and lane widths had an effect on the amount of vehicular lateral wander and rut development.

The amount of lateral wander will be influenced to certain extent by the design and layout of the road. Cross section design will determine verge and lane widths while longitudinal design will determine the amount of horizontal and vertical curvature. The design will also determine the need for central or side guardrail barriers. Vehicular factors, such as type and speed, will also have an effect how a vehicle is driven and influence the amount of vehicular wander. Driver behaviour will also be affected to some extent by the surrounding environment.

Variations in the amount of lateral wander will have a direct effect on the rate of surface wear and will influence where stresses and strains are distributed in the pavement structure. Pavements will deteriorate at a quicker rate where lateral wander is constricted by a confining design.

Quantifying these variations will provide data that may prove useful in surface wear and deformation prediction models. Vehicle position data may also prove to be valuable when determining cross sectional design factors such as joint placement and lane and verge widths. Furthermore, this is important information for tyre/pavement rolling resistance research where rolling resistance indicators use measured road condition characteristics. The results from this project can be used to help guide where in the road these characteristics should be measured.

2. Aim

The objective during the project was to investigate, quantify and analyse variations of vehicle lateral position and lateral wander on the Swedish road network.

During the previous project mentioned in Chapter 1, causes of accelerated degradation on barrier separated roads were investigated. Part of the investigation involved comparing the amounts of vehicle lateral wander associated with conventional and barrier separated road types. This was achieved by carrying out vehicle position surveys on a sample of road types that carry around 65% of traffic in Sweden. In order to achieve the aim in this project, additional position data was required for the road types that carry the remaining 35% of traffic.

3. Method

In order to be able to investigate and quantify vehicle lateral position and lateral wander, it was necessary to determine how vehicles actually utilised the available road space.

To achieve this, a series of lateral position surveys were carried out on various types of road design common in the Swedish road network:

- conventional (7.7 m wide to 9.4m wide),
- motorway,
- barrier separated (2+1),
- barrier separated (1+1),
- four lane, and
- conventional (13 m - wide side verge).

Surveys provided position data related to the front wheels of approximately 271,000 vehicles. The data was split into three main groups depending on axle track width (refer to Appendix 1):

- light vehicles (1.5 m track width),
- HGV Group 1 (1.8 m track width), and
- HGV Group 2 (2.1 m track width).

Using average position and standard deviation values, the distribution of lateral position, average position, and variation of lateral position could be summarised for each vehicle group.

Limitations with the measurement system did not allow tyre contact (with road surface) widths to be measured. Standard tyre widths were therefore assumed. Common tyre sizes were used for each of the three vehicle categories:

- light vehicles – 205 size = 175 mm surface contact width,
- HGV Group 1 – 295 size = 265 mm surface contact width, and
- HGV Group 2 – 385 size = 355 mm contact surface width.

Incorporating the assumed tyre widths with the average position and variation of lateral position data, it was possible to plot transverse tyre tracking diagrams for each of the three vehicle categories.

3.1. Measurement 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 to provide position data to the nearest millimetre.



Photograph 1. Coaxial 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 Sörensen, 1995).



Photograph 2. Traffic analyser TA89 and charge amplifier. (Photo. Terence McGarvey)

Surveys are normally carried out continuously over two to three days but durations can be adjusted to suit different traffic volumes. For safety reasons, motorway surveys are usually confined to the nearside lane. This is not considered to be a problem as the majority of traffic tends to be driven in this lane. To ensure data between sites is comparable, it is important to avoid locations directly before or after slip roads, junctions or sharp bends. Due to the use of studded tyres in Sweden, the system is not suitable for use during the winter months.

3.2. Distribution of lateral position (right hand side of front tyres)

Survey data was split into three main groups depending on the vehicles front axle track width (refer to Appendix 1):

- light vehicles (1.5 m),
- HGV Group 1 (1.8 m), and
- HGV Group 2 (2.1 m).

The following diagrams, Figures 1 and 2, show how position data for these three groups can be used to indicate the distribution of lateral position or wheel path of the right hand side of front tyre. If tyre contact (with road surface) widths were known, values could have been adjusted to show the distribution of the centre of each tyre. All positions are relative to the right hand side road edge.

Density curves look quite symmetrical and have a distinctive bell shapes with single peaks. This is consistent with normal distribution. The three sigma rule states that around 68% of values associated with a normal distribution fall within one standard deviation from the mean; about 95% of the values lie within two standard deviations; and about 99.7% are within three standard deviations. Even with near normal distribution, at least 98% of the variables should fall within three standard deviations.

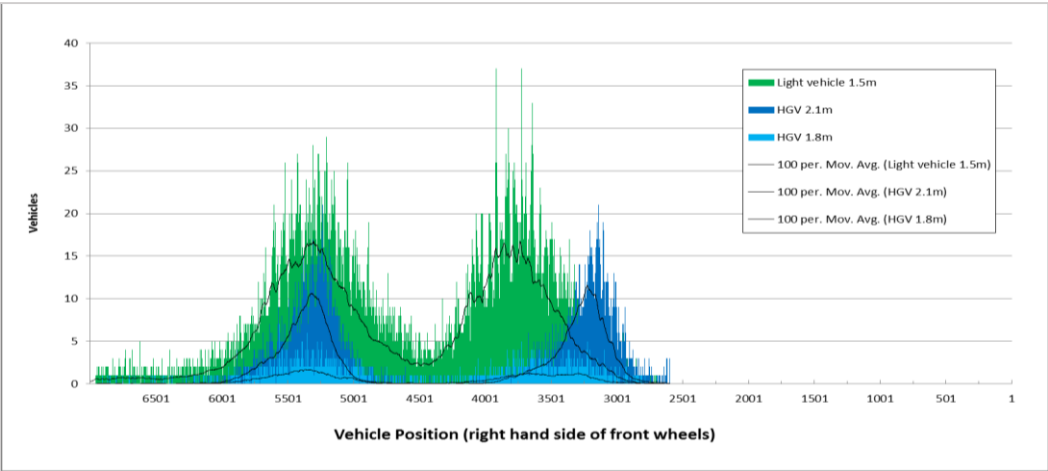


Figure 1. Distribution of Lateral Position – E4 Motorway.

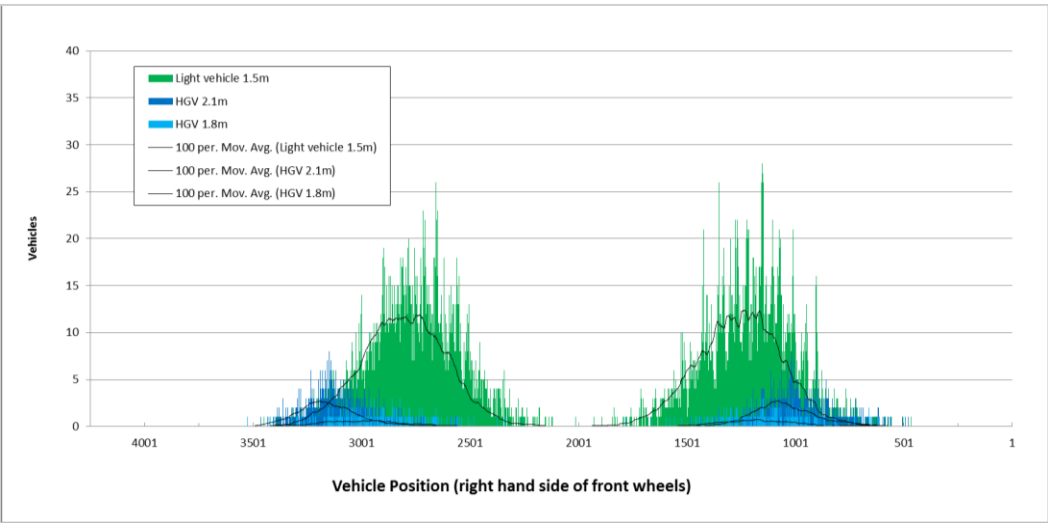


Figure 2. Distribution of Lateral Position – Road 23/34 "1+1" Barrier Separated Road.

3.3. Average position and standard deviations

Using the distribution of lateral position data, it was possible to determine the average position (\bar{x}) and standard deviations (s).

As tyre contact widths could not be measured, a common front tyre size was assumed for each of the three vehicle categories:

- Light vehicles – 205 size = 175 mm surface contact width,
- HGV Group 1 – 295 size = 265 mm surface contact width, and
- HGV Group 2 – 385 size = 355 mm surface contact width.

The example below (Figure 3), assuming a 205 tyre size (175 mm contact width), 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.

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 shows that off-side tyre positions are confined within a 1711 mm band width. Near-side tyre positions are confined within a 1765 mm band width.

It should be noted that these bandwidths include the assumed 175 mm tyre contact width. For pavement design purposes, where the effect of lateral loading is introduced, the distribution of the wheel path (centre point of a single or double tyre) should be considered.

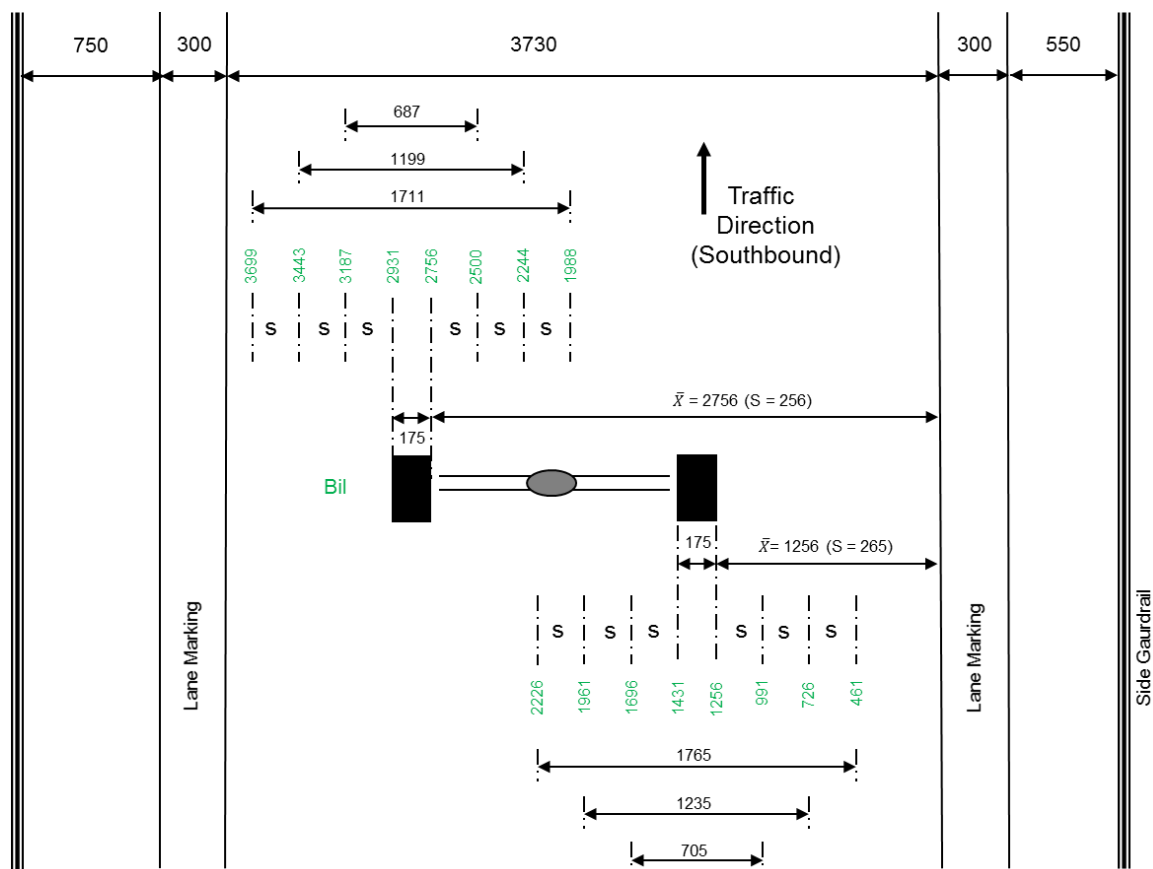


Figure 3. Average Lateral Position and Standard Deviation (light vehicle example).

3.4. Tyre tracking

Using the average position and standard deviation data, it was possible to plot the front tyres average position and extent of lateral wander for the three vehicle categories. The scaled drawing example below (figure 4) shows average front tyre position (full lines) and one, two and three standard deviations (intermittent lines) for each vehicle category.

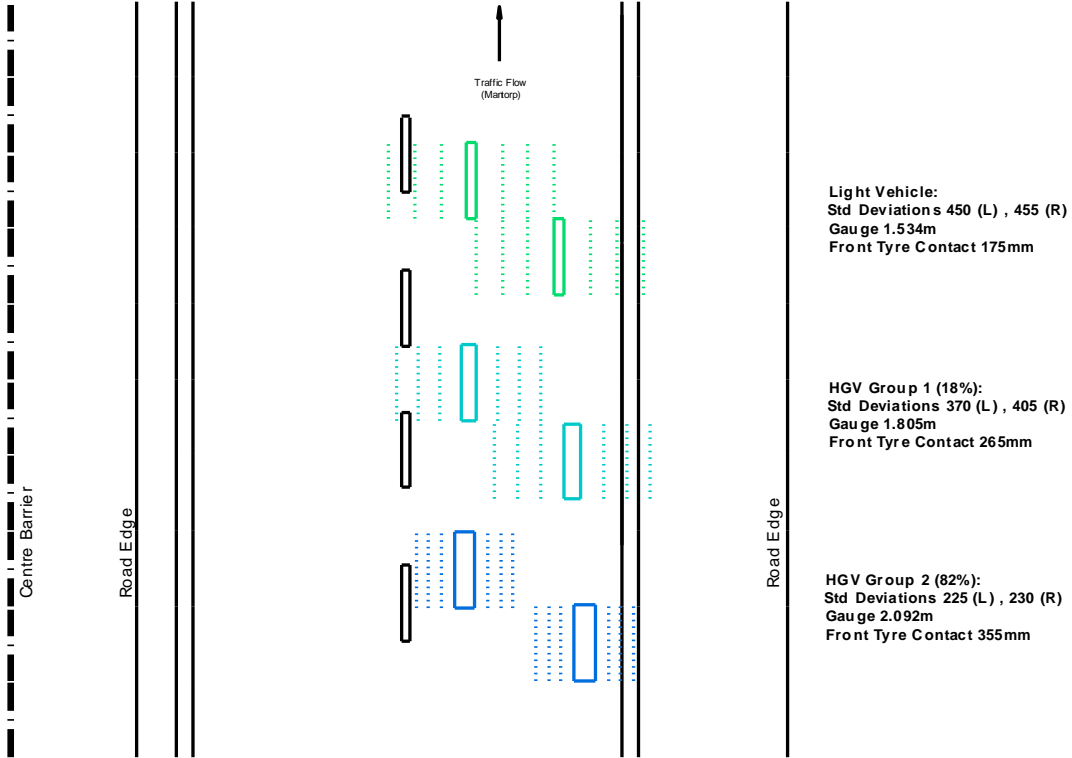


Figure 4. Tyre position distribution – E4 Motorway, Linköping.

In this example (figure 4), it can be seen that the offside (left hand side) tyre average position was similar for all three vehicle groups. This suggests that, for motorway type roads, maximum rutting will occur in the offside tyre track if the road structure has uniform resistance against surface wear and deformation. The rut is also likely to have a near symmetrical shape. On the nearside (right hand side), tyre positions were not the same. This is likely to result in an unsymmetrical rut shape being formed with the maximum rut depth occurring in the HGV group 2 position. The overlapping that occurs between the offside and nearside tyres (light vehicles and HGV Group 1 only) will also have some effect on rut formation.

The suggestion can be confirmed by examining the cross section profile at the surveyed location (figure 5). Rut development is discussed further in chapter 4.8.

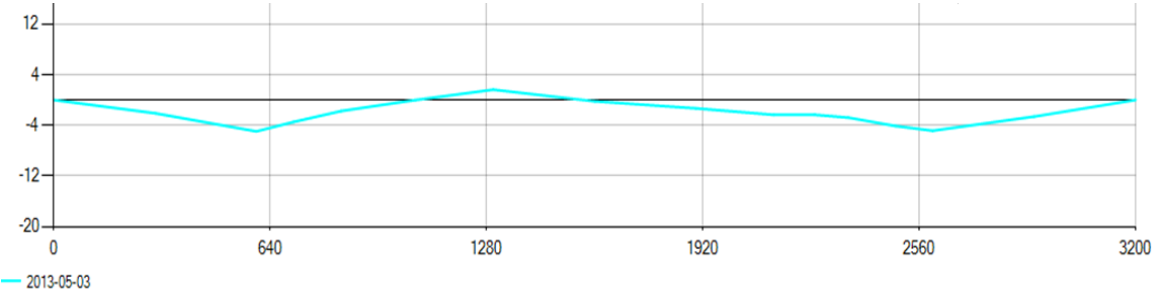


Figure 5. Actual Cross Section Profile - E4 Motorway at Ref 5b (Trafikverket PMSv3).

3.5. Position survey locations

The Swedish national road network can be divided into groups depending on category and type. The tables below show road lengths and usage (vehicle kilometres) in 2015.

Table 1. State and Local Authority Maintained Roads (trafikverket.se).

Road	Km	Vehicle km (milliard km)
State Maintained	98,500	58
Local Authority Maintained	42,200	24

Table 2. Road Category 2015 (trafikverket.se).

Category	Km	Vehicle km (milliard km)
European Route	6,700	23 (40%)
National Route	8,900	14 (24%)
Primary Rural Road	10,800	9 (16%)
Other Rural Road	72,100	12 (20%)
Total	98,500	58

Table 3. Road Type 2015 (trafikverket.se).

Road Type	Km	Vehicle km (milliard)
Motorway	2,050 (2%)	17 (29%)
Dual Carriageway (barrier separated)	410 (390)	1 (2%)
4 lane carriageway	200	1 (2%)
Conventional road (barrier separated)	95,500 (97%) (2,410)	33 (57%)

Only around 2% of the national road network is constructed to motorway standard. However, approximately 29% of all vehicle traffic is carried on this type of road. On the other hand, conventional road types make up 97% of the road network and carry 57% of traffic.

Position surveys were carried out on a selection of the above road types.

Position surveys were carried out at the fifteen locations detailed in Table 4. Twenty-one surveys provided data on approximately 271,000 vehicles.

Table 4. Position Survey Locations.

Ref	Road No	Location	Road Category	Road Type	AADT (% HGV)
1a 1b	34	Linköping	National Route	Barrier Separated (2+1)	5220 (8%) 5480 (8%)
2a 2b	636	Linköping	Secondary Rural	Barrier Separated (2+1)	3175 (5%) 3215 (6%)
3a 3b	23/34	Skeda Udde	National Route	Barrier Separated (1+1)	2675 (12%)
4	E6	Uddevalla	European Route	Motorway	11350 (15%)
5a 5b	E4	Linköping	European Route	Motorway	11430 (15%)
6a 6b	50	Mjölby	National Route	Four Lane (2+2 no barrier)	3965 (16%)
7a 7b	796	Gistad	Secondary Rural	Conventional (13.0 m)	2025 (11%)
8	Bergsvägen	Berg	Secondary Rural	Conventional (9.4 m)	4355 (6%)
9	19	Tomelilla	National Route	Conventional (9.2 m)	1260 (16%)
10	9/11	Simrishamn	National Route	Conventional (9.0 m)	2760 (9%)
11	23/34	Brokind	National Route	Conventional (8.8 m)	2595 (11%)
12	34	Linköping	National Route	Conventional (8.6 m)	3150 (11%)
13	19	Skåne-Tranås	National Route	Conventional (8.0 m)	1705 (16%)
14	19	Brösarp	National Route	Conventional (7.9 m)	2060 (17%)
15	135	Gamleby	Primary Rural	Conventional (7.7 m)	180 (12%)

4. Results and discussion

A summary of the amount of vehicular lateral wander (standard deviation of average position) is provided in the following table. The sample size (number of recorded vehicles) for each survey is also stated.

Table 5. Vehicular Lateral Wander and Sample Size.

Ref	Road No	Road Type	Std Dev (mm)						Sample Size (vehicles)
			Light Vehicle		HGV1		HGV2		
			Left	Right	Left	Right	Left	Right	
1a	34	2+1	270	270	245	250	215	215	41766
1b	34	2+1	375	375	290	325	225	225	22523
2a	636	2+1	255	260	225	225	190	185	30610
2b	636	2+1	400	400	265	305	260	270	25871
3a	23/34	1+1	190	195	195	190	140	150	6998
3b	23/34	1+1	200	200	195	190	150	145	7740
4	E6	Motorway	380	365	310	330	255	255	24142
5a	E4	Motorway	450	455	370	405	225	230	8452
5b	E4	Motorway	405	405	315	355	220	220	18118
6a	50	Four Lane	270	265	250	270	220	220	3658
6b	50	Four Lane	270	280	235	285	215	225	4149
7a	796	Conventional	355	355	410	425	395	380	12796
7b	796	Conventional	400	400	410	425	430	415	4475
8	Bergsvägen	Conventional	315	315	300	300	285	260	20074
9	19	Conventional	350	355	290	325	240	240	3383
10	9/11	Conventional	375	380	360	375	270	275	6165
11	23/34	Conventional	320	310	295	305	240	215	9079
12	34	Conventional	300	295	265	280	205	210	12251
13	19	Conventional	300	300	250	285	195	195	4400
14	19	Conventional	315	315	260	265	210	215	4290
15	135	Conventional	265	270	305	300	260	240	754

Total 271694

Max	450	455	410	425	430	415
Min	190	195	195	190	140	145

Further information on cross section dimensions, distribution of lateral position, average lateral position, variation of lateral position, and vehicle tracking is provided in Appendix 2.

4.1. Standard deviations of average position

As previously mentioned in Chapter 3.3, the three sigma rule states that nearly all values will be contained within three standard deviations of the mean. By applying this rule, it can be assumed that nearly all tyre positions will be contained within three standard deviations of the average tyre position. The standard deviation of a vehicle's position is a good indicator of the variation in lateral position.

In the following figure, standard deviation values have been plotted for the offside tyres of three main groups of vehicles:

- light vehicles (1.5 m track width),
- HGV Group 1 (1.8 m track width), and
- HGV Group 2 (2.1 m track width).

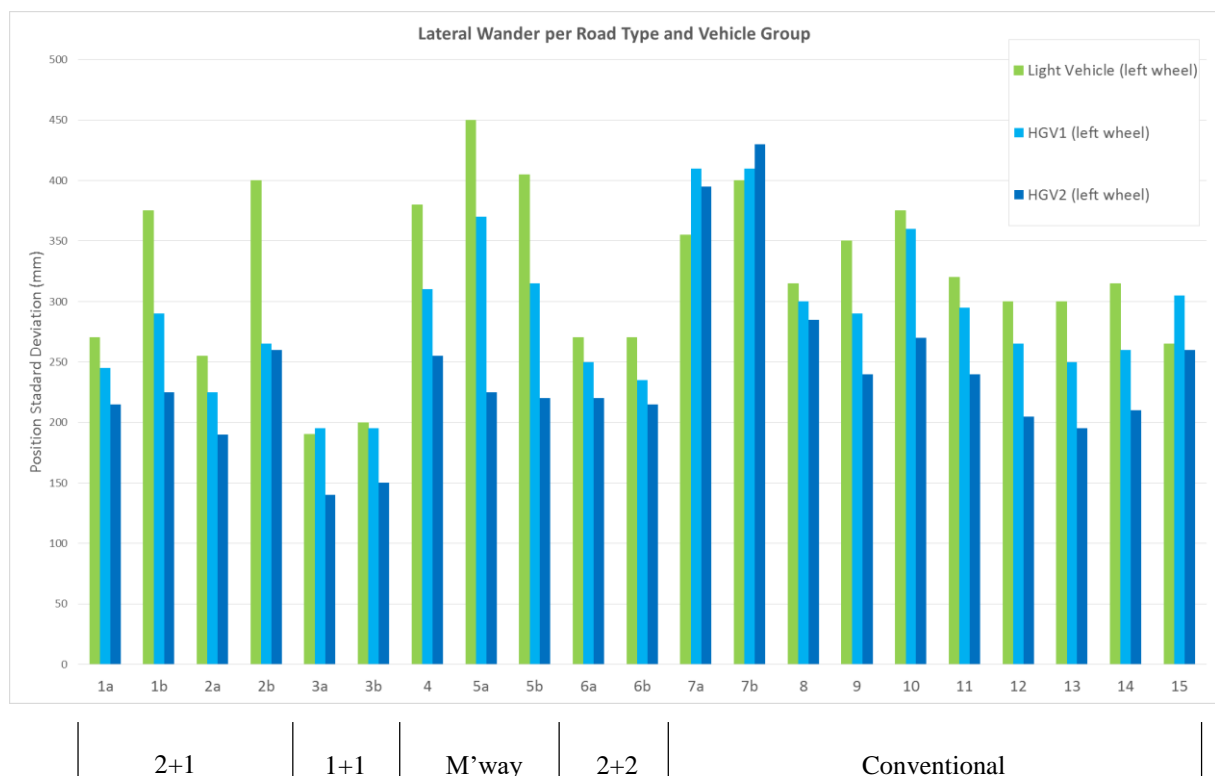


Figure 6. Lateral Wander per Road Type and Vehicle Group.

In the majority of the results, vehicles with smaller axle track widths tended to have more lateral wander. The exceptions were at locations 7 and 15.

Traffic observations at location 7 revealed that slower, heavier vehicles tended to move into the 2.8 m wide side verge to allow faster vehicles to over-take. This could help explain the higher lateral wander values associated with the HGV groups.

The observed order of the variation for different vehicle categories at location 15 differs from other locations with similar properties. Traffic volume at location 15 was very low, however, a statistical test showed that the variation for HGV1 was not significantly greater than that for light vehicles. It cannot be rejected that the order should in fact be the same as in locations 8 to 14.

4.2. 2+1 road type

With regard to “2+1” road types, Figure 7, clear differences in the amount of lateral wander can be seen between the single lane sections (ref 1a and 2a) and the double lane sections (ref 1b and 2b).

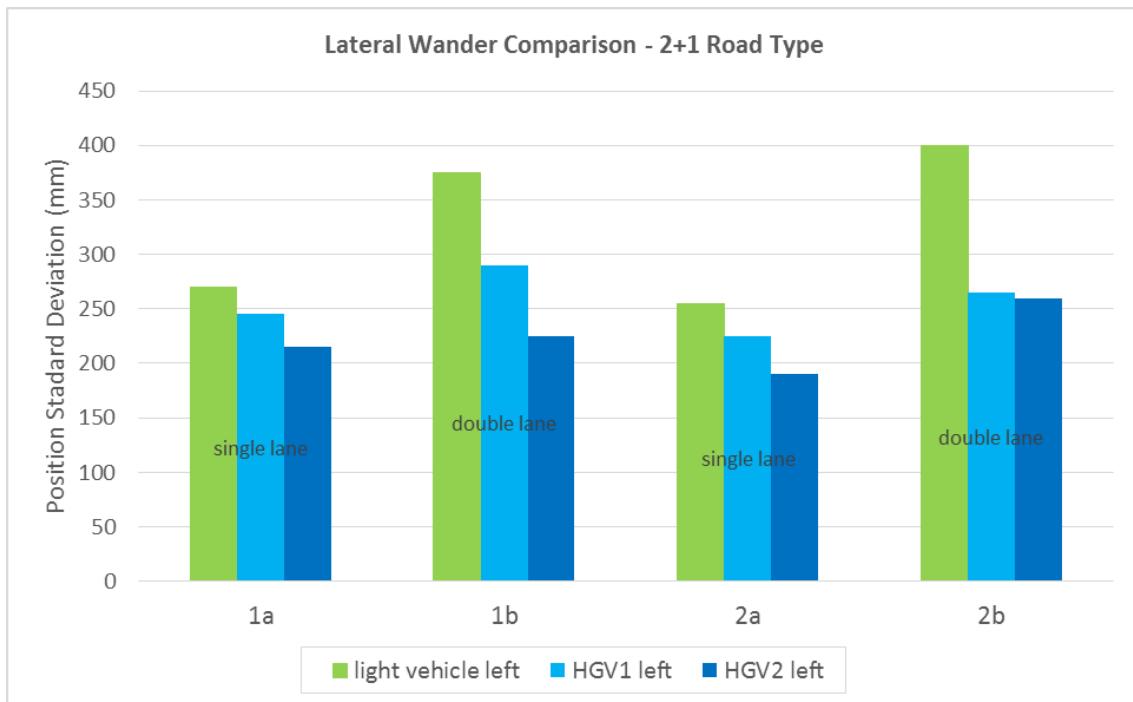


Figure 7. Lateral Wander Comparisons – “2+1” Road.

It is therefore assumed that road degradation rates in the single lane sections will be higher than in the double lane sections. This can be confirmed by analysing rut depth and traffic volume data obtained from the Swedish Road Administrators (Trafikverket) PMSv3 database – Figure 8.

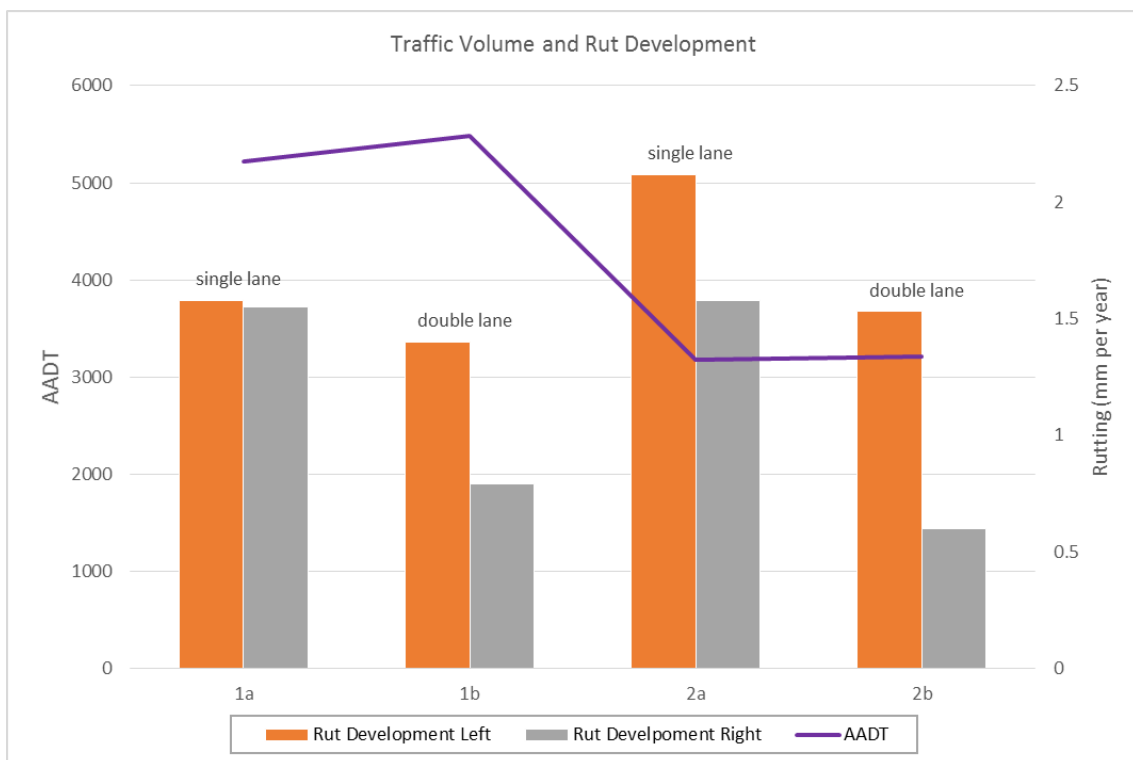


Figure 8. Traffic volume and rut development rates – “2+1” Road (Trafikverket PMSv3).

4.3. Conventional road converted to “1+1” barrier separated road

Comparisons between reference 3a and 3b (9 m wide 1+1 barrier separated) and reference 10 (9 m wide conventional road) show that lateral wander is much lower on the barrier separated road layout.

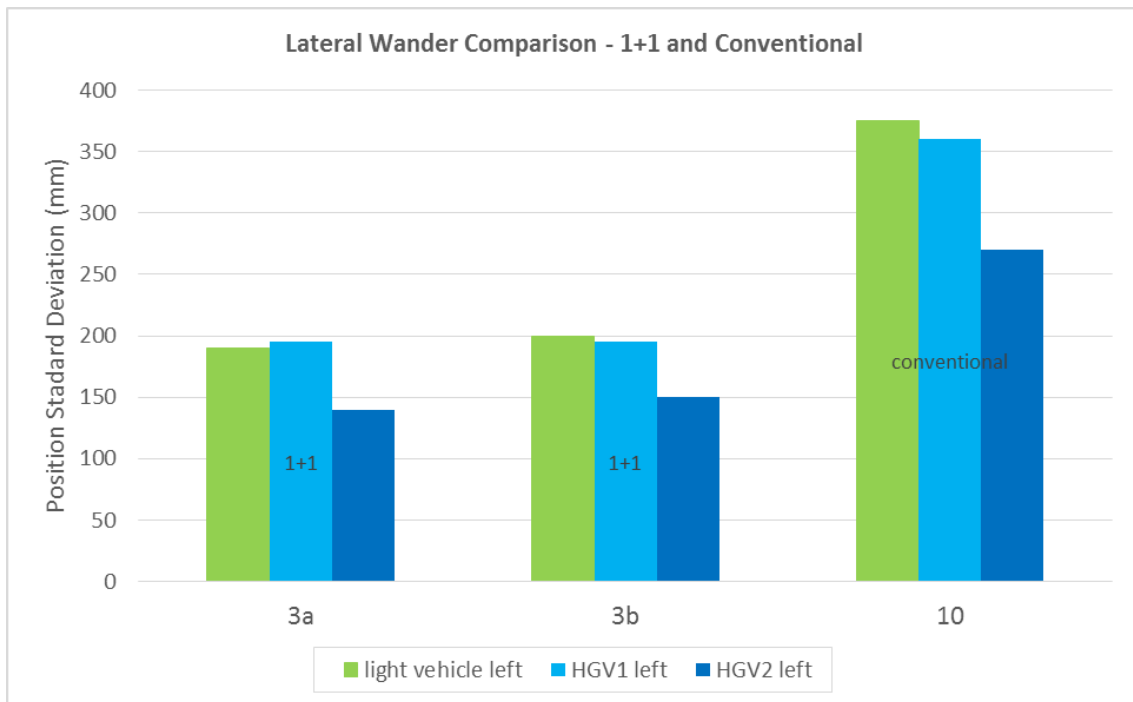


Figure 9. Lateral Wander Comparisons – 9 m “1+1” with 9m Conventional Road.

Figure 9 illustrates the considerable reduction in vehicle lateral wander that occurs when a 9 m wide conventional road is converted into a 9 m wide “1+1” barrier separated road.

Reference 3a and 3b were converted to a barrier separated road in 2011 and partly resurfaced during 2014. Insufficient road surface survey data meant that it was not possible to compare rut development rates before and after the conversion.

However, the fact that resurfacing work was required three years after conversion, may give an indication of how severe confinement of traffic can accelerate degradation rates.

4.4. Double lane sections

Lateral wander values for light vehicles on a “2+2” road type (ref 6a and 6b) were considered to be quite low. These should have been comparable with values on the double lane sections of a “2+1” road type (ref 1b and 2b).

A possible explanation for this is that the narrower side verge, associated with ref 6, may have had some confining effect on the amount of lateral wander.

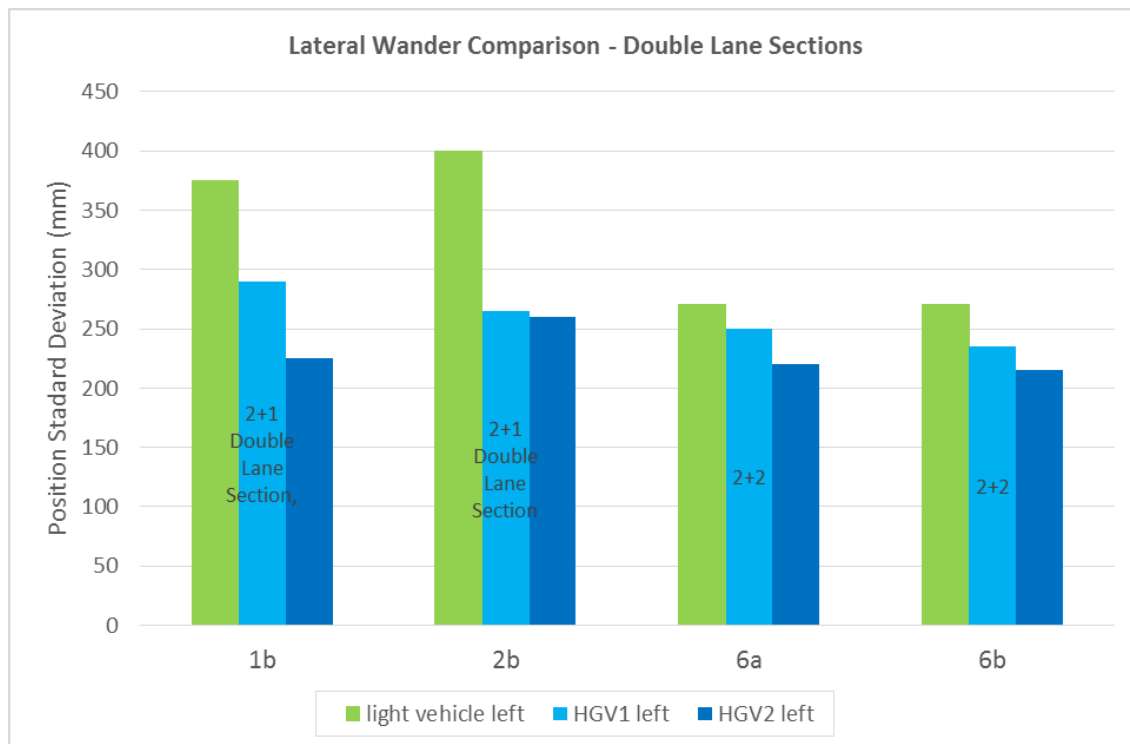


Figure 10. Lateral Wander Comparisons – Double Lane Sections.

4.5. Effect of lane type and side verge widths

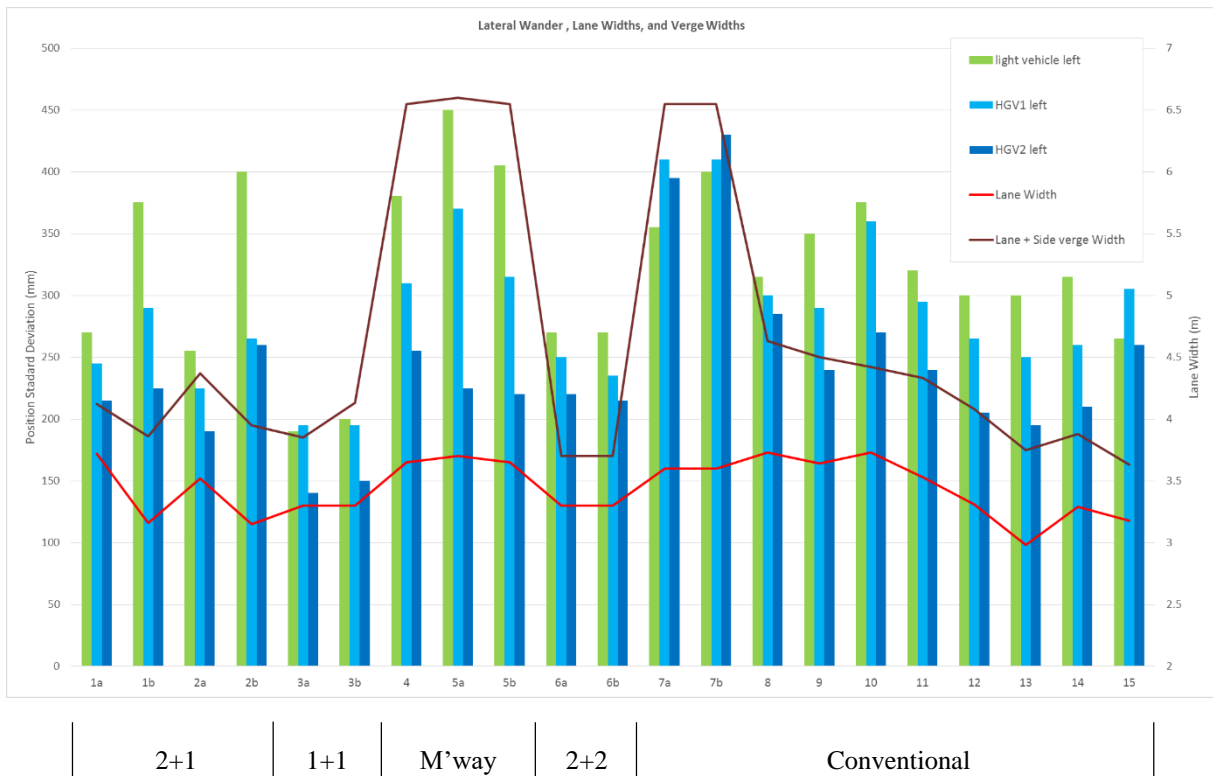


Figure 11. Lateral Wander, Lane Widths, and Side Verge Widths.

Regarding “2+1” and motorway road types (reference 1b, 2b, 4, 5a and 5b), the presence of the adjacent second lane is likely to have a positive effect and increase the amount of lateral wander.

For motorway road types (reference 4, 5a and 5b), the presence of a wide side verge is also likely to have influenced the higher values associated with light vehicle and HGV Group 1 values.

The effect of a wide side verge can also be seen in conventional road types 7a and 7b.

4.6. Narrow lane and side verge widths

The very low lateral wander values associated with the “1+1” sections (ref 3a and 3b) can be attributed to narrower lane widths and the close proximity of the central barrier.

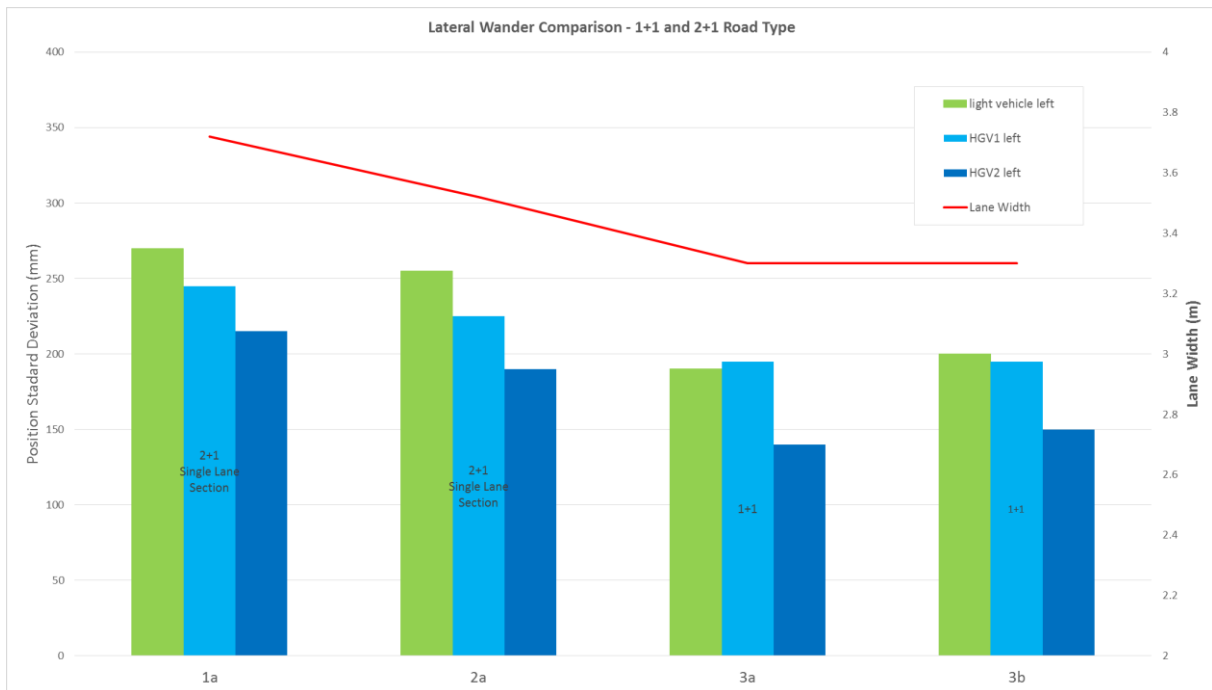


Figure 12. Single Lane Section Comparisons – 1+1 and 2+1 Road Types.

With regard to reference 3a and 3b, lane widths were found to be narrower. In addition, the distance from the offside lane edge marking to the central barrier was only 400 mm. The same dimension in comparable road types, reference 1a and 2a, was 800 mm and 1100 mm respectively.

4.7. Lateral wander and lane widths

With reference to conventional road types, the following figure shows trends between the amount of lateral wander and the widths of lanes and side verges.

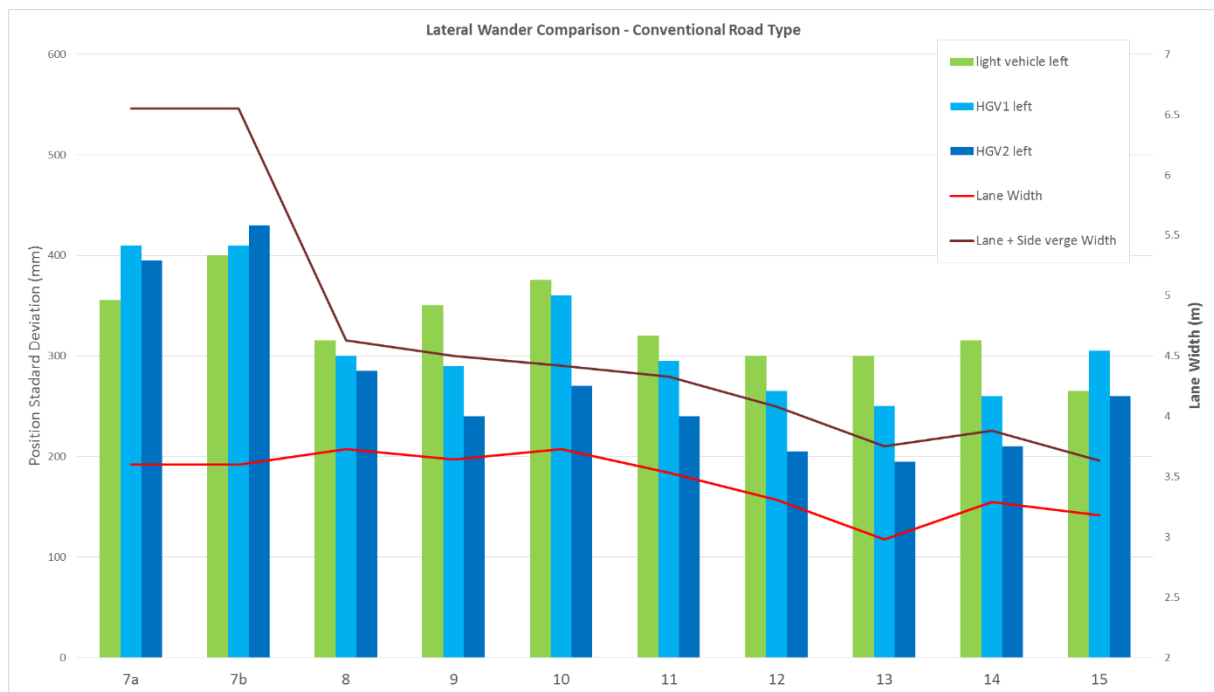


Figure 13. Conventional Road Types – Lateral Wander and Lane Widths.

With the exception of references 7a, 7b and 15, there is a connection between lane width and the amount of vehicle lateral wander – especially with the HGV Group 2 category.

The wide side verges associated with reference 7a and 7b have probably contributed to the high amount of lateral wander.

As stated previously in Chapter 4.1, traffic volume at reference 15 was very low. Variations for HGV1 were not significantly greater than that for light vehicles and it cannot be rejected that the order should in fact be the same as in locations 8 to 14.

4.8. Rut development rates

Vehicle position is a factor that has an influence on rut formation. An example of this can be demonstrated in Figure 14. The approximate positions of Light Vehicles, HGV Group 1, and HGV Group 2 have been added to the cross section profile previously detailed in Chapter 3.4.

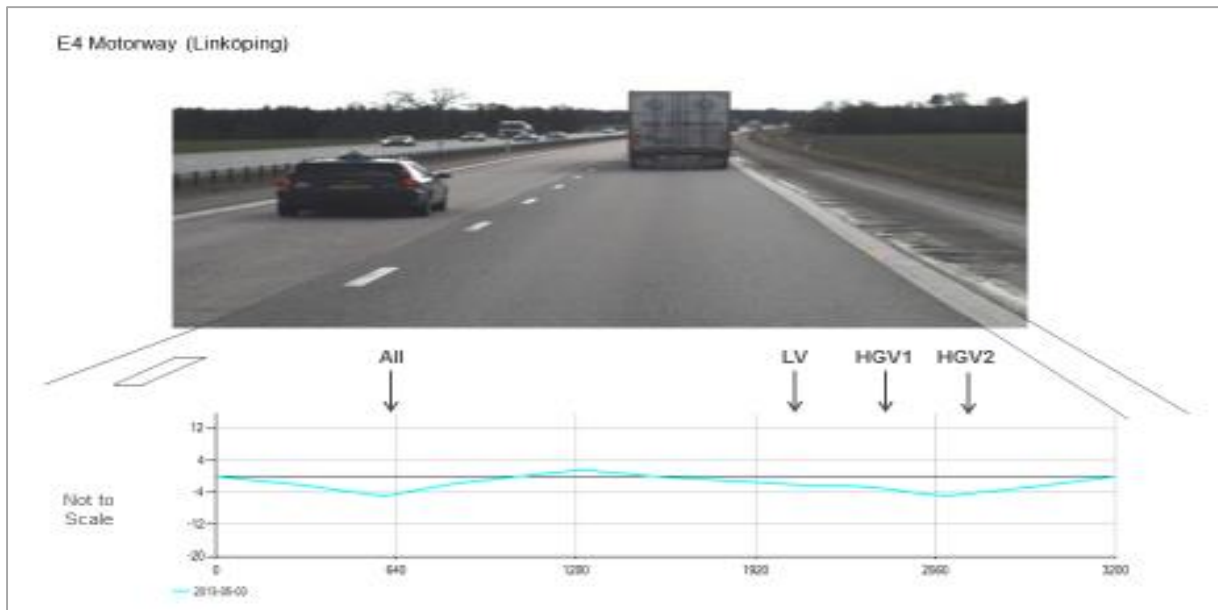


Figure 14. Actual Cross Section Profile - E4 Motorway at Ref 5b (Trafikverket PMSv3).

The figure shows two different types of rut formation. On the vehicles offside, surface wear and deformation is confined to a deeper, narrower, symmetrical type of rut. The nearside rut is much wider and not as deep – surface wear and deformation are not confined to the same track.

Using data extracted from the Swedish Road Administrators (Trafikverket) PMSv3 Database, it was possible to calculate rut development rates and traffic volumes for the examples shown below in Figure 15. Due to insufficient data, it was not possible to calculate rates for references 3, 6 and 7. Reference 4 formed part of a test road so rates were considered not to be comparable. Results show that in every case, development rates were higher in the left hand side rut.

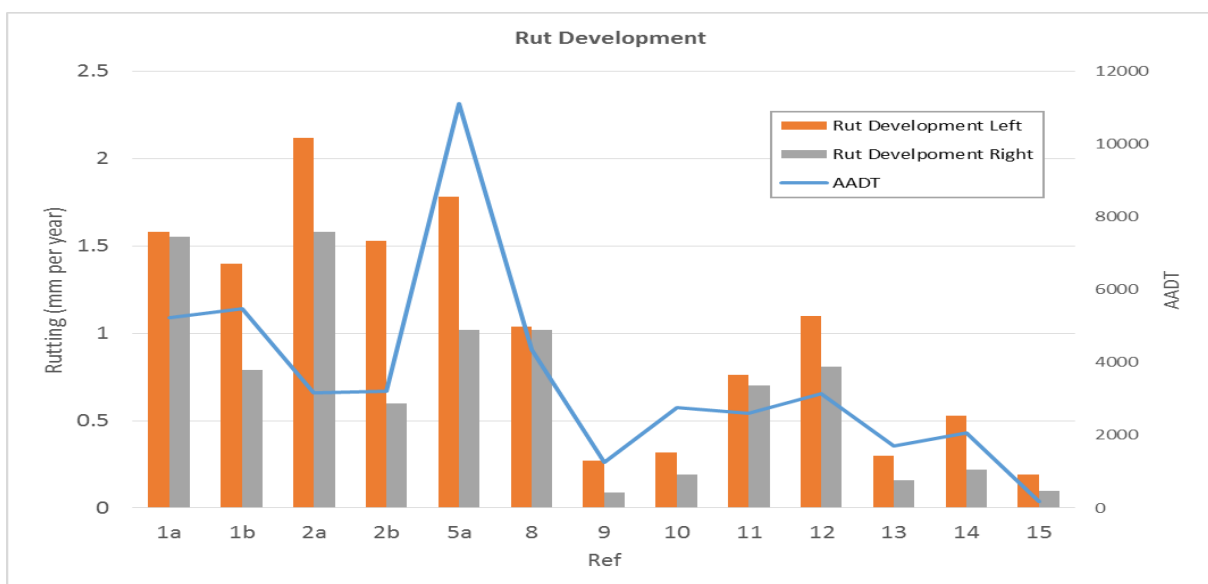


Figure 15. Traffic Volume and Rut Development.

5. Conclusions and further work

Vehicle position and amount of vehicular lateral wander will have an effect on the rate of pavement wear. Pavements will deteriorate at a quicker rate where lateral wander is constricted by a confining design.

A method to determine the lateral position of a vehicle has been used to provide vehicle position data on a range of common road types found on the Swedish road network. Twenty-one sets of survey data provided information on over 271,000 vehicles. The information was split into three vehicle groups depending on the axle track width.

Using the survey data, it was possible to calculate and plot the distribution of lateral position, the average position, and the variation of lateral position (lateral wander) for each group. In order to try and determine the distribution of wheel paths, the centre point of a single or double wheel, development work on the “Z” measuring system is being carried out (McGarvey, 2016) so that tyre widths and types can also be determined.

Factors such as lane type, lane width, verge width, total width, and close proximity of guardrail all had some influence on vehicle position and amount of lateral wander.

The extent of lateral wander varied quite considerably. Values associated with light vehicles varied between 455 mm and 190 mm. Commercial traffic values were lower and ranged between 430 mm and 140 mm. These are significant variations and should be considered when planning reconstruction or maintenance work.

The information contained in this report may prove to be very useful when trying to interpret road surface characteristic data recorded in databases such as Trafikverkets PMSv3. It may also prove useful when calculating rates of surface wear and deformation in prediction models such as VTIs Surface Wear Model (Wågberg och Jacobson, 2007) and PEDRO (Oscarsson & Said, 2011).

The information may also be important for tyre/pavement rolling resistance research where rolling resistance indicators use measured road condition characteristics. The results can be used to help guide where in the road these characteristics should be measured.

Around forty different types of vehicle were identified by the measurement system. If required, it is possible to study the position and behaviour of a particular type of vehicle.

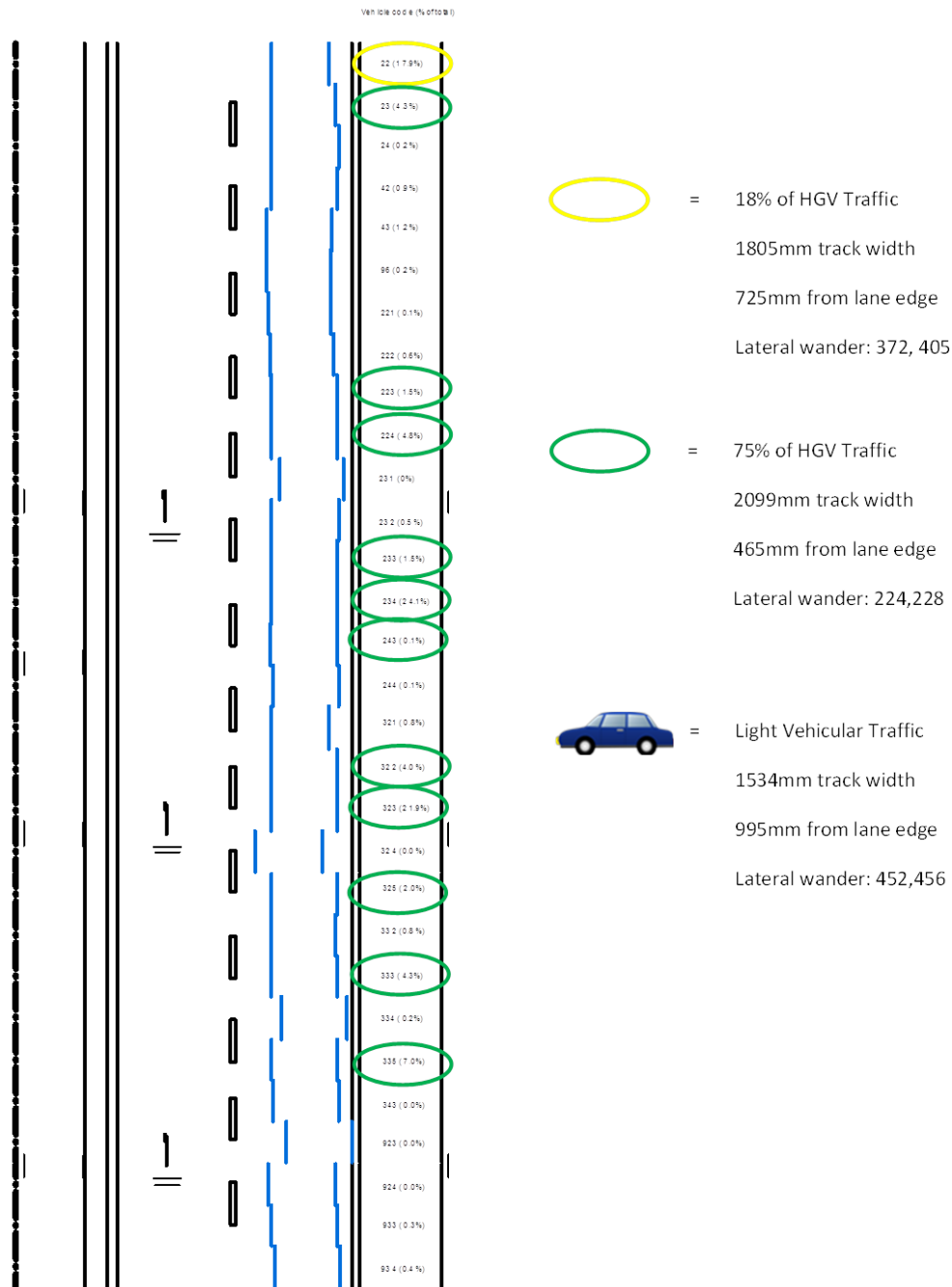
Surveys were carried out on relatively straight, open road sections. It is possible that vehicle position and amount of lateral wander will be affected by road curvature and surroundings. The extent of these effects is unknown and may warrant further investigation.

References

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Appendix 1

It was possible to split HGV's into two groups depending on vehicle track width. HGV's classified as vehicle code "22" had an average axle track width of 1.805m and, in the case below, accounted for 18% of all HGV traffic.



Road E4 (motorway) near Linköping:

Average position of HGV types and percentage of total.

Appendix 2

Ref 1a: Road 34, Linköping, National Route, Barrier Separated (2+1)

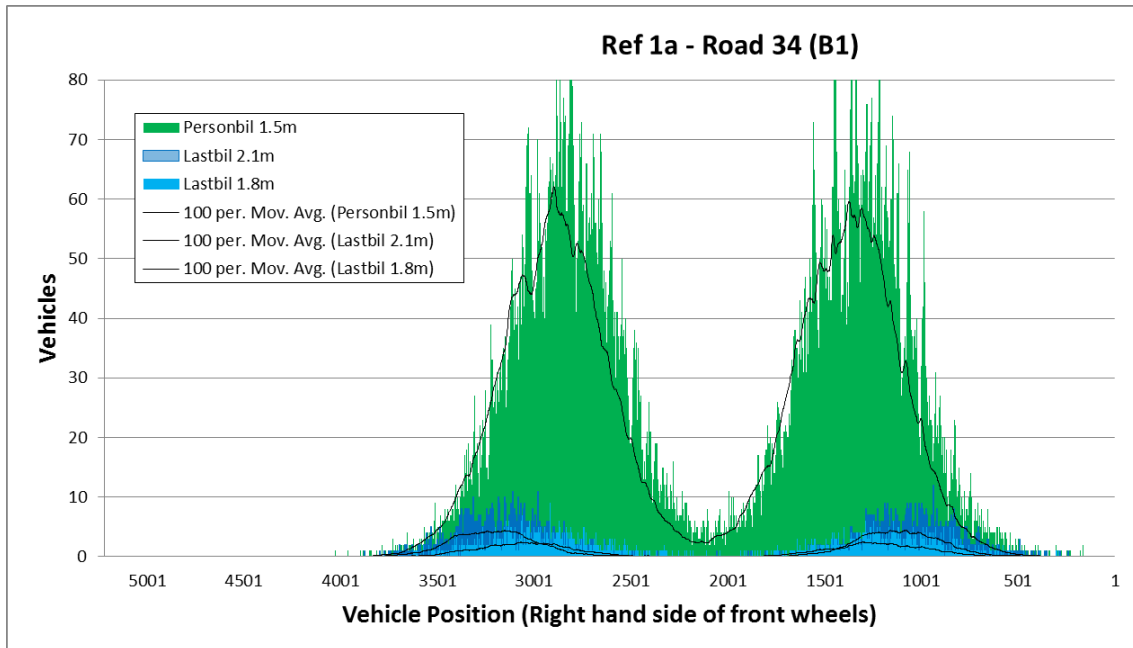


Figure 16. Ref 1a – Distribution of Lateral Position.

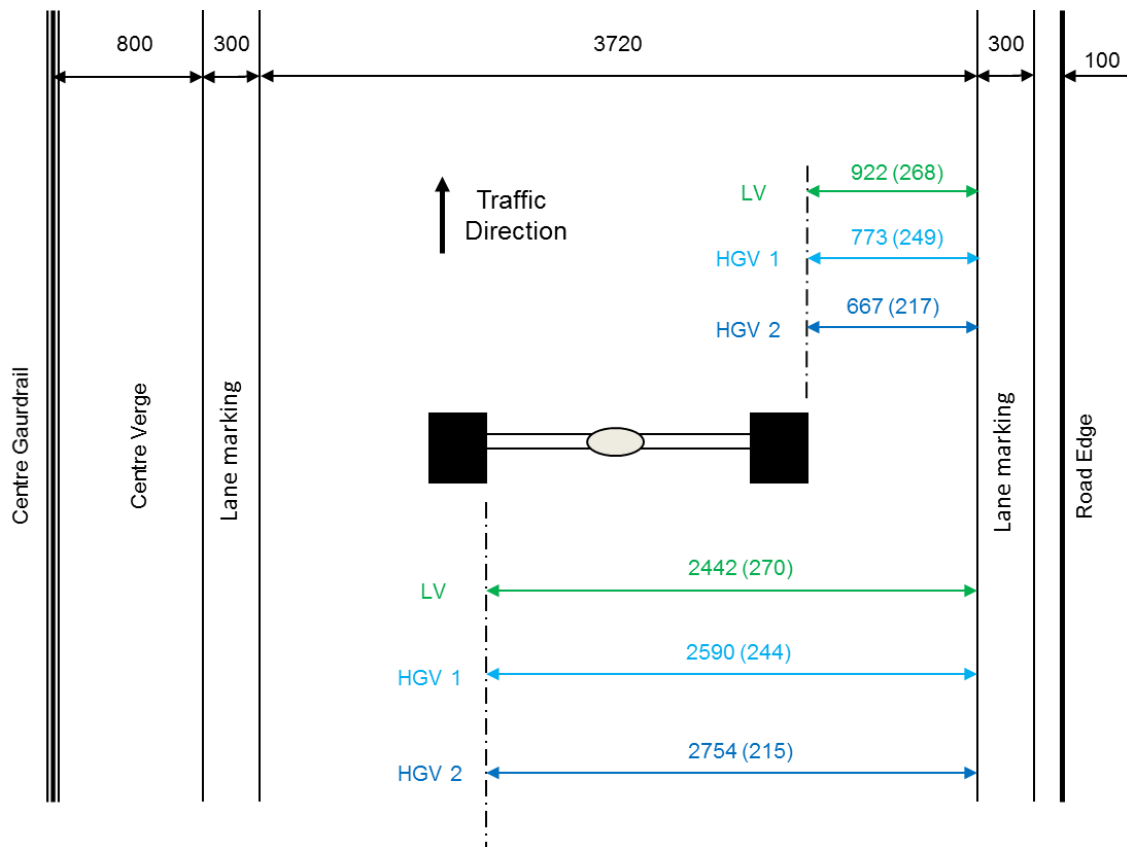


Figure 17. Ref 1a - Average Lateral Position and Standard Deviation.

Tyre tracking, assuming the following front tyre contact (with road surface) widths:

- light vehicles – 205 size = 175 mm surface contact width,
- HGV Group 1 – 295 size = 265 mm surface contact width, and
- HGV Group 2 – 385 size = 355 mm contact surface width.

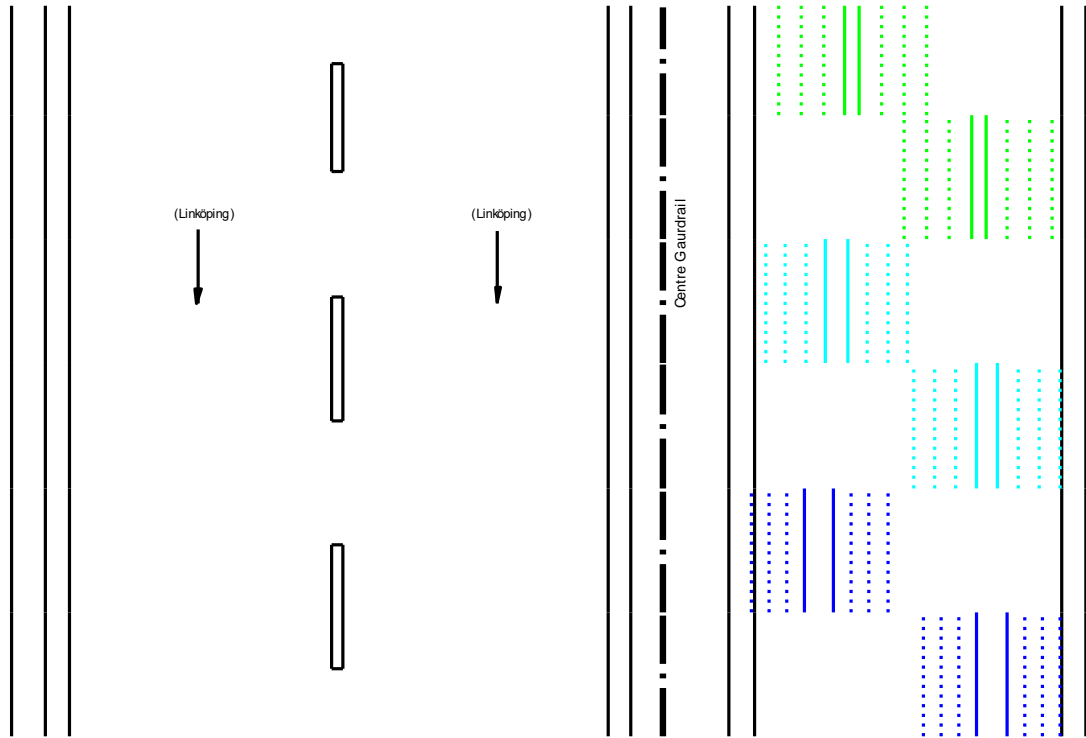


Figure 18. Ref 1a – Tyre Tracking in Single Lane Section.



Photograph 3. Ref 1a. (Photo. Terence McGarvey).

Ref 1b: Road 34, Linköping, National Route, Barrier Separated (2+1)

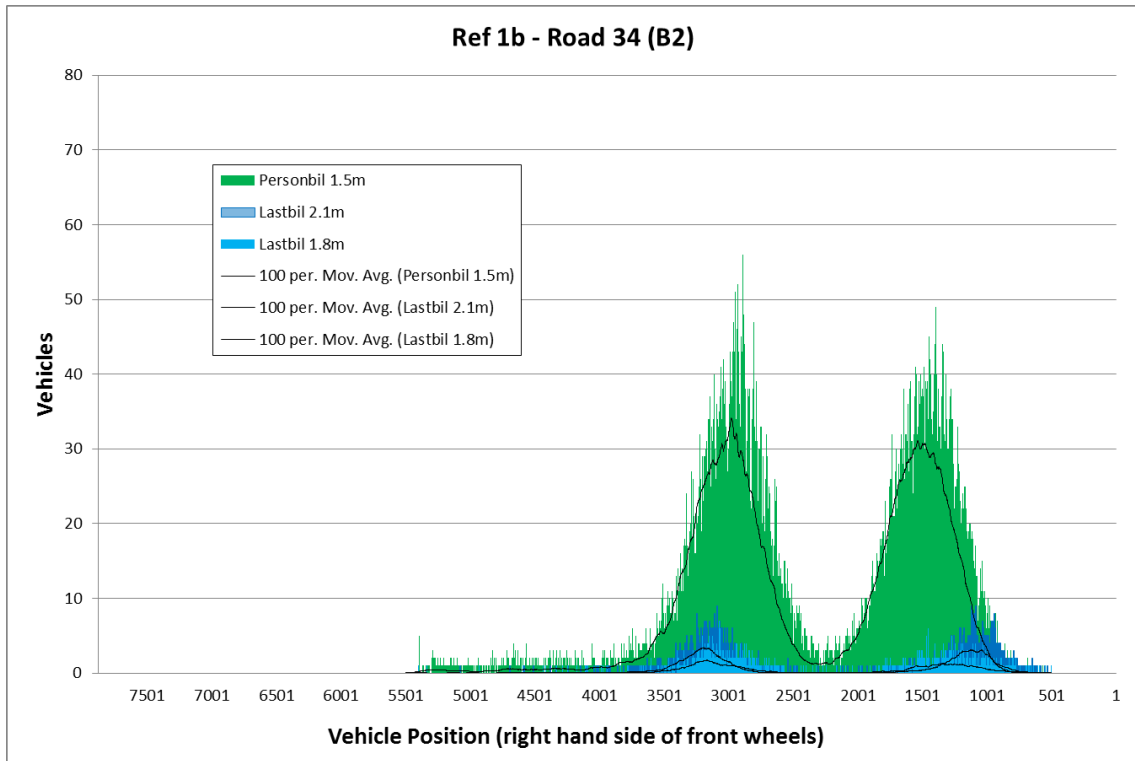


Figure 19. Ref 1b – Distribution of Lateral Position.

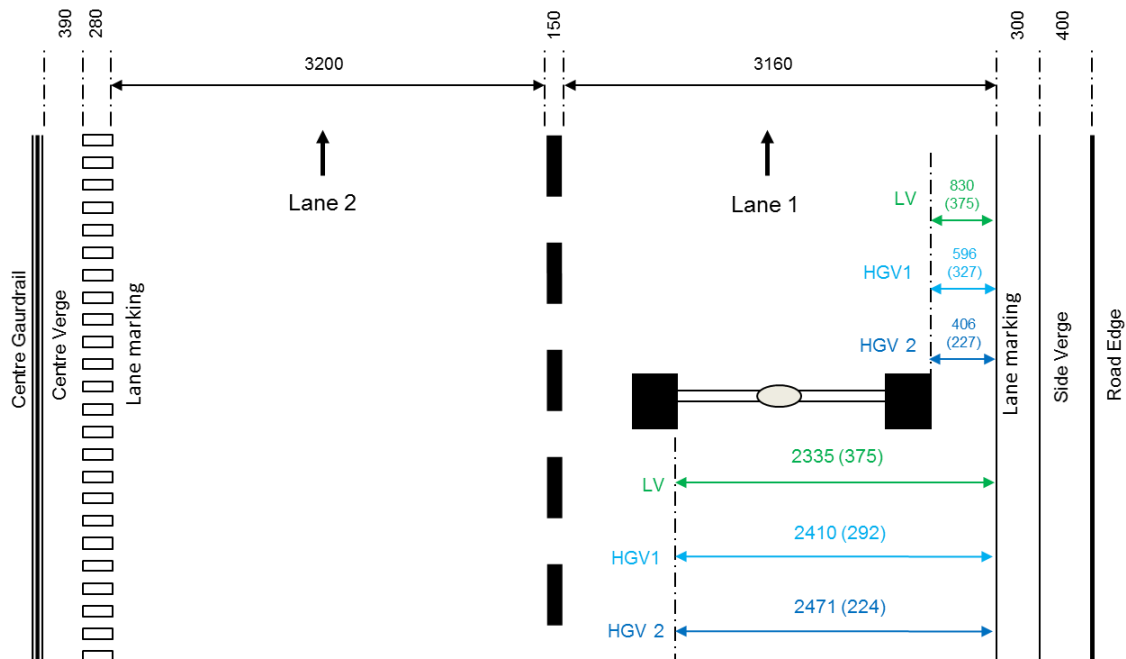


Figure 20. Ref 1b - Average Lateral Position and Standard Deviation.

Tyre tracking, assuming the following front tyre contact (with road surface) widths:

- light vehicles – 205 size = 175 mm surface contact width,
- HGV Group 1 – 295 size = 265 mm surface contact width, and
- HGV Group 2 – 385 size = 355 mm contact surface width.

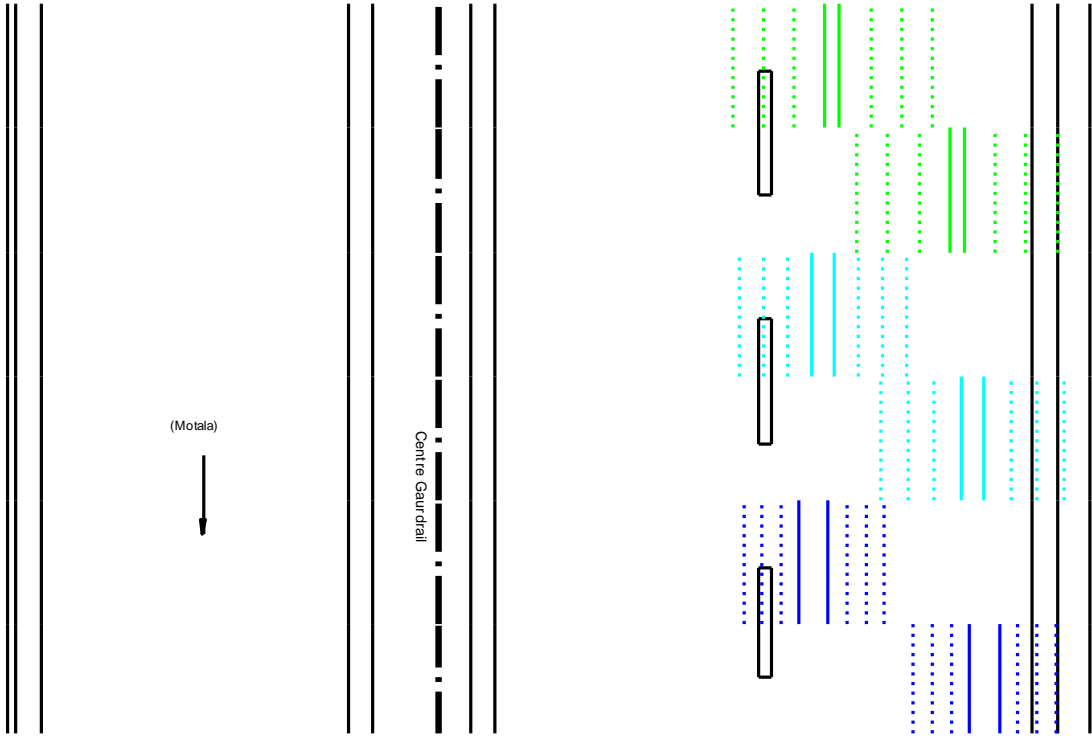


Figure 21. Ref 1b – Tyre Tracking in Double Lane Section.



Photograph 4. Ref 1b. (Photo. Terence McGarvey).

Ref 2a: Road 636, Linköping, Secondary Rural Road, Barrier Separated (2+1)

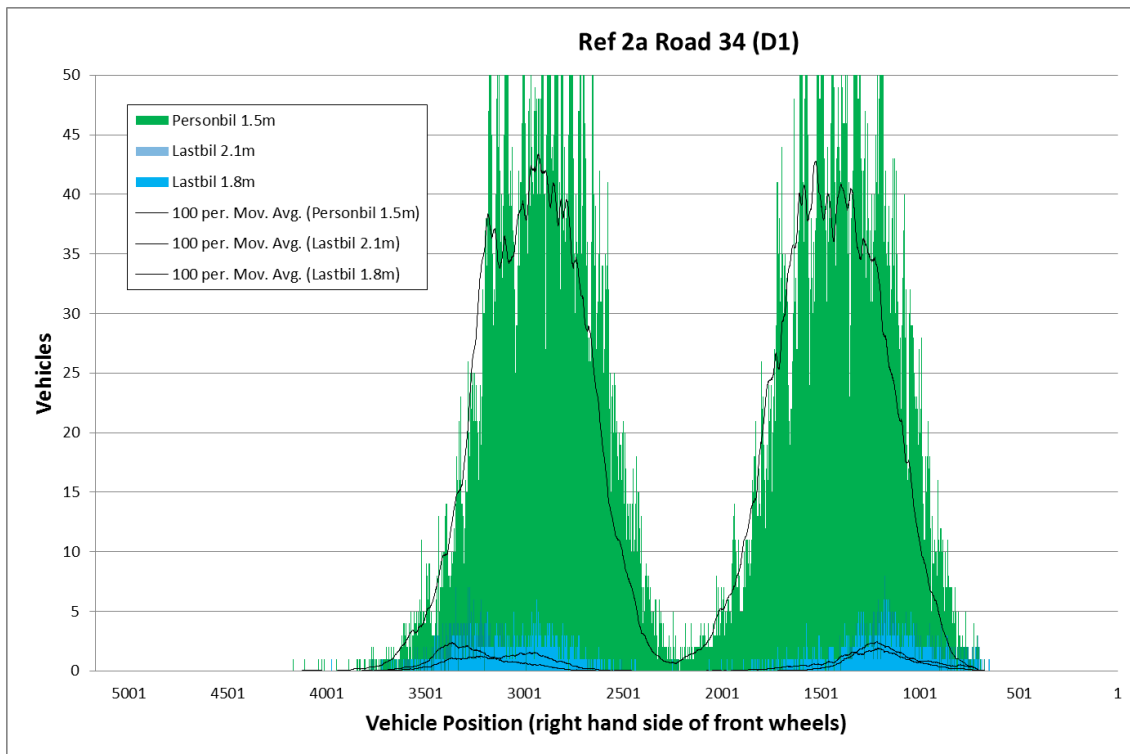


Figure 22. Ref 2a – Distribution of Lateral Position.

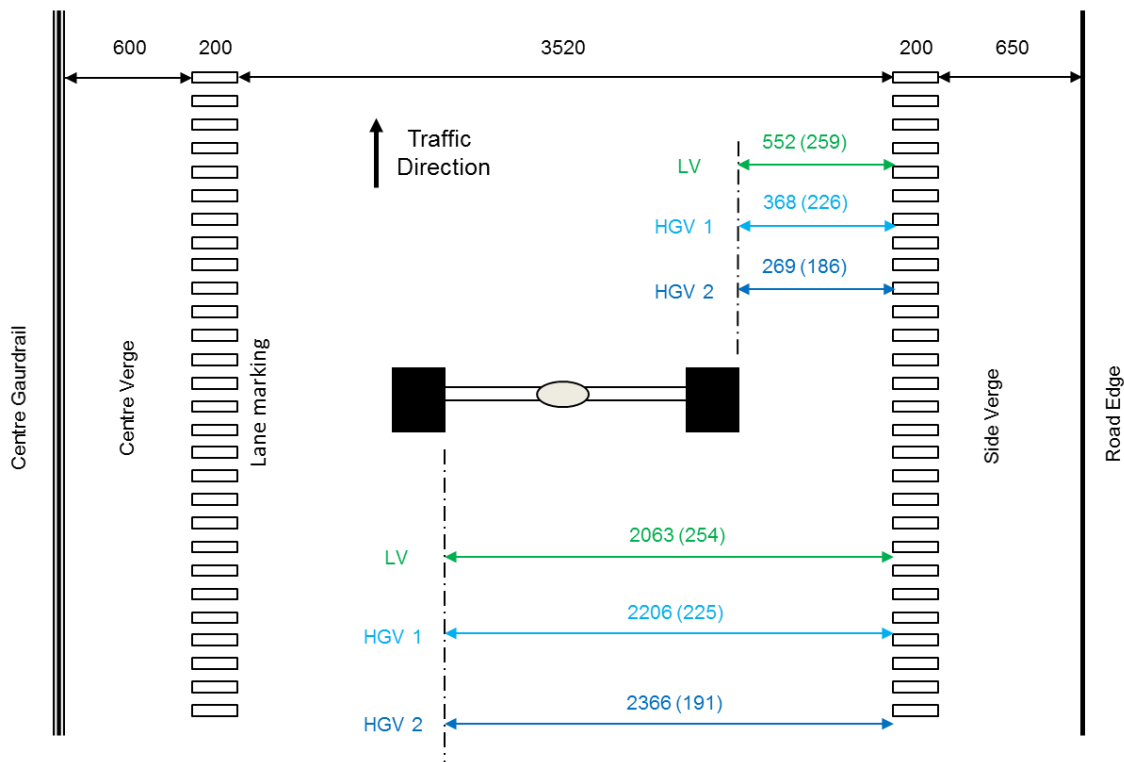


Figure 23. Ref 2a - Average Lateral Position and Standard Deviation.

Tyre tracking, assuming the following front tyre contact (with road surface) widths:

- light vehicles – 205 size = 175 mm surface contact width,
- HGV Group 1 – 295 size = 265 mm surface contact width, and
- HGV Group 2 – 385 size = 355 mm contact surface width.

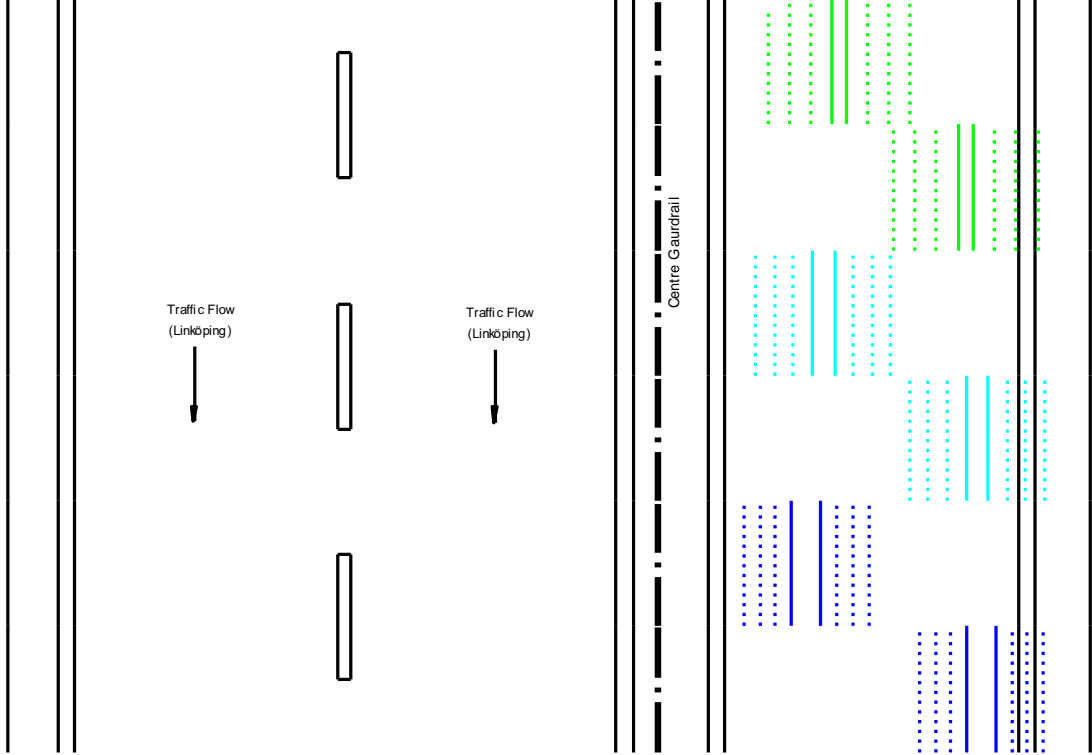


Figure 24. Ref 2a – Tyre Tracking in Single Lane Section.



Photograph 5. Ref 2a. (Photo. Terence McGarvey).

Ref 2b: Road 636, Linköping, Secondary Rural Road, Barrier Separated (2+1)

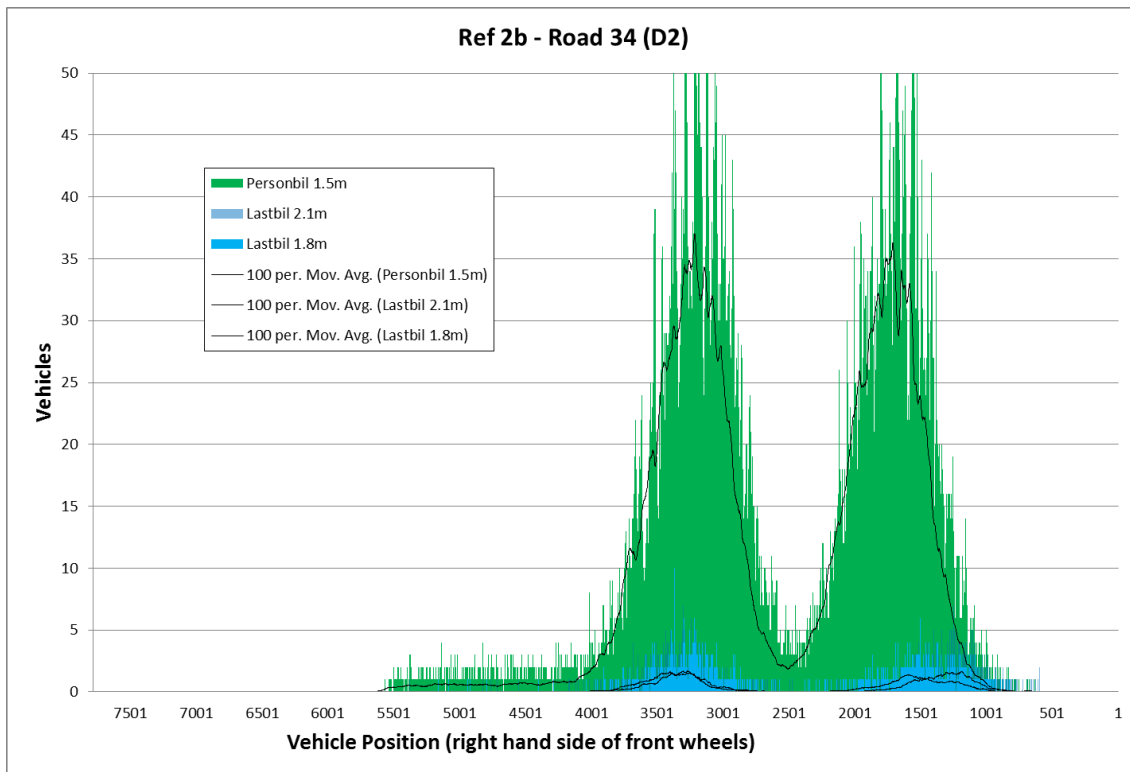


Figure 25. Ref 2b – Distribution of Lateral Position.

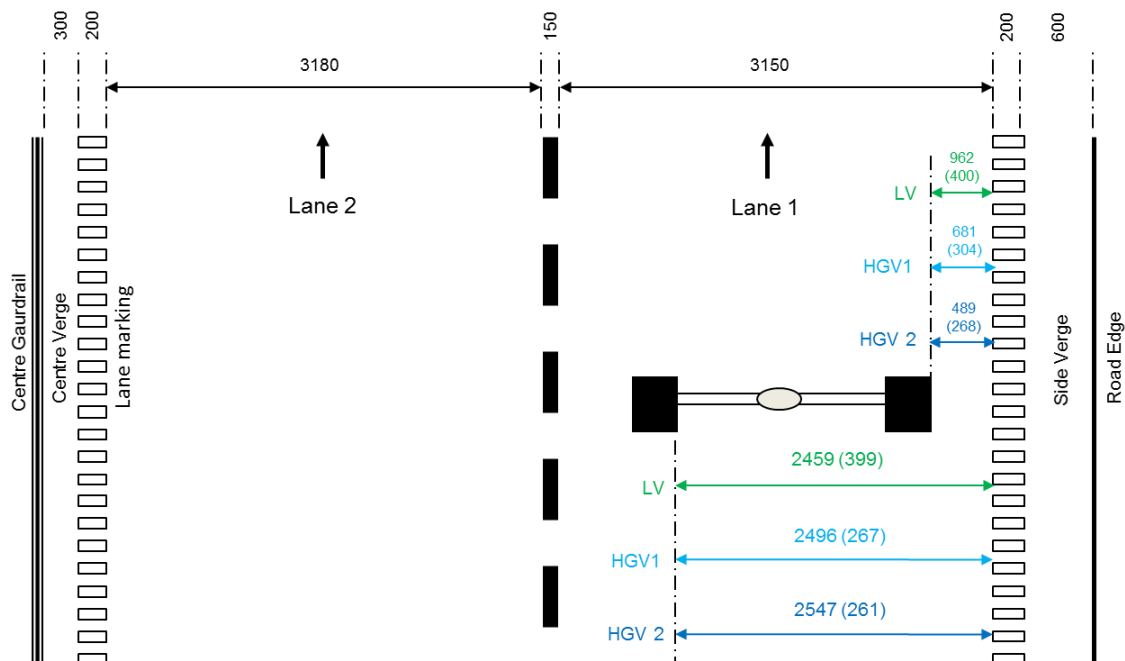


Figure 26. Ref 2b - Average Lateral Position and Standard Deviation.

Tyre tracking, assuming the following front tyre contact (with road surface) widths:

- light vehicles – 205 size = 175 mm surface contact width,
- HGV Group 1 – 295 size = 265 mm surface contact width, and
- HGV Group 2 – 385 size = 355 mm contact surface width.

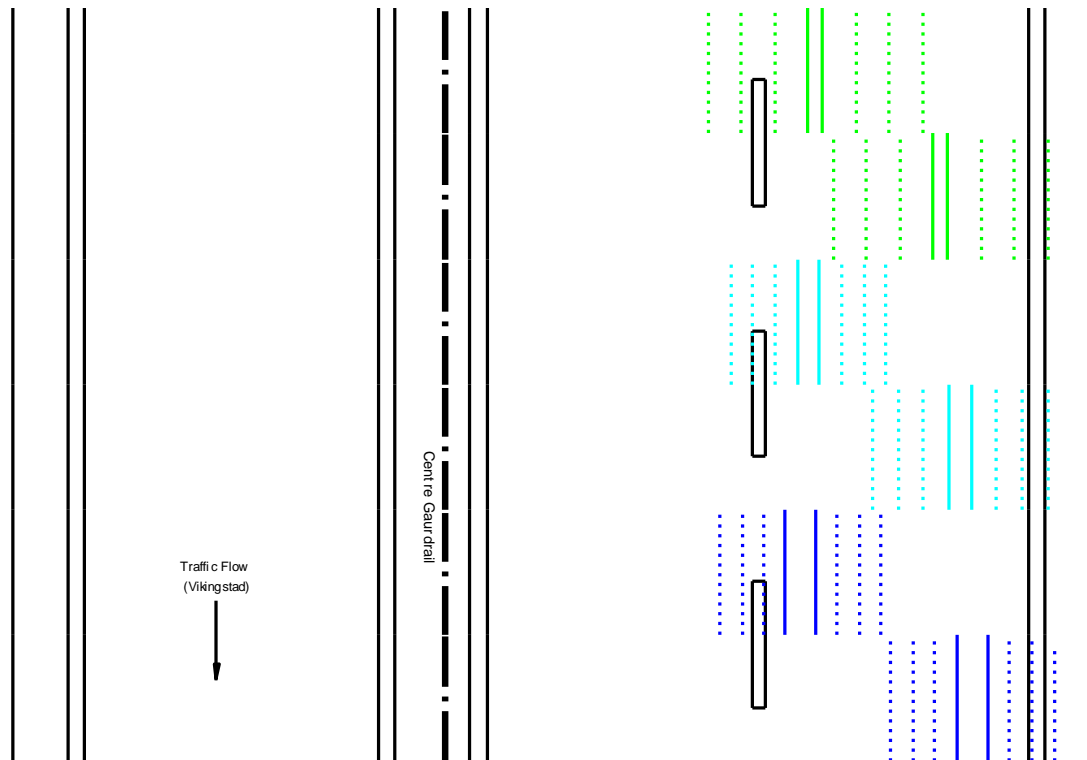


Figure 27. Ref 2b – Tyre Tracking in Double Lane Section.



Photograph 6. Ref 2b. (Photo. Terence McGarvey).

Ref 3a: Road 23/34, Skeda Udde, National Route, Barrier Separated (1+1)

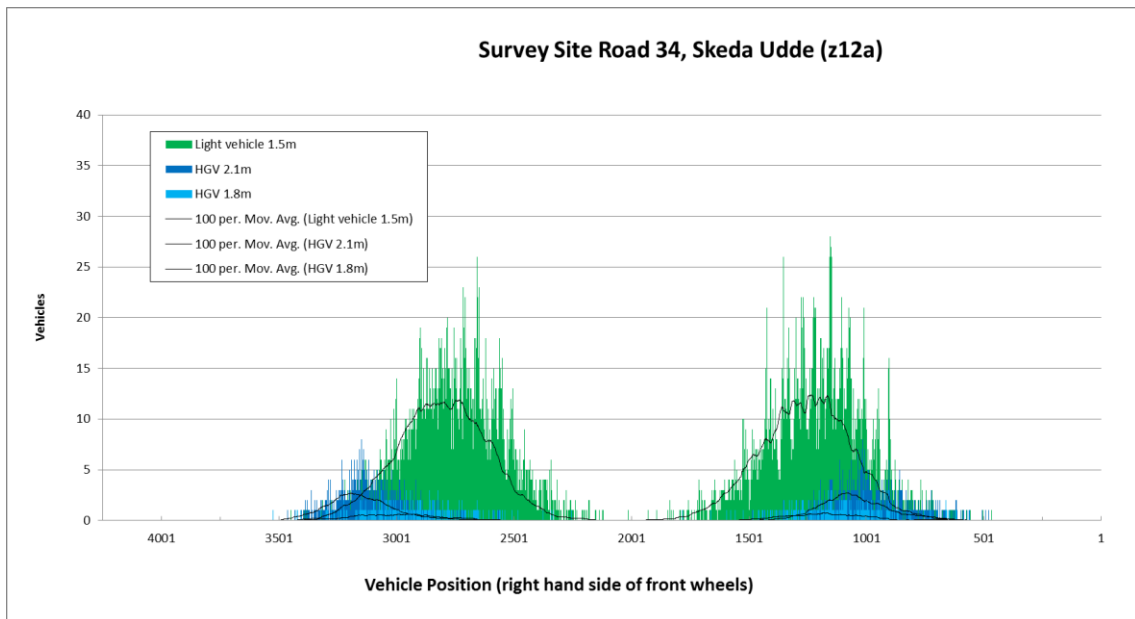


Figure 28. Ref 3a – Distribution of Lateral Position.

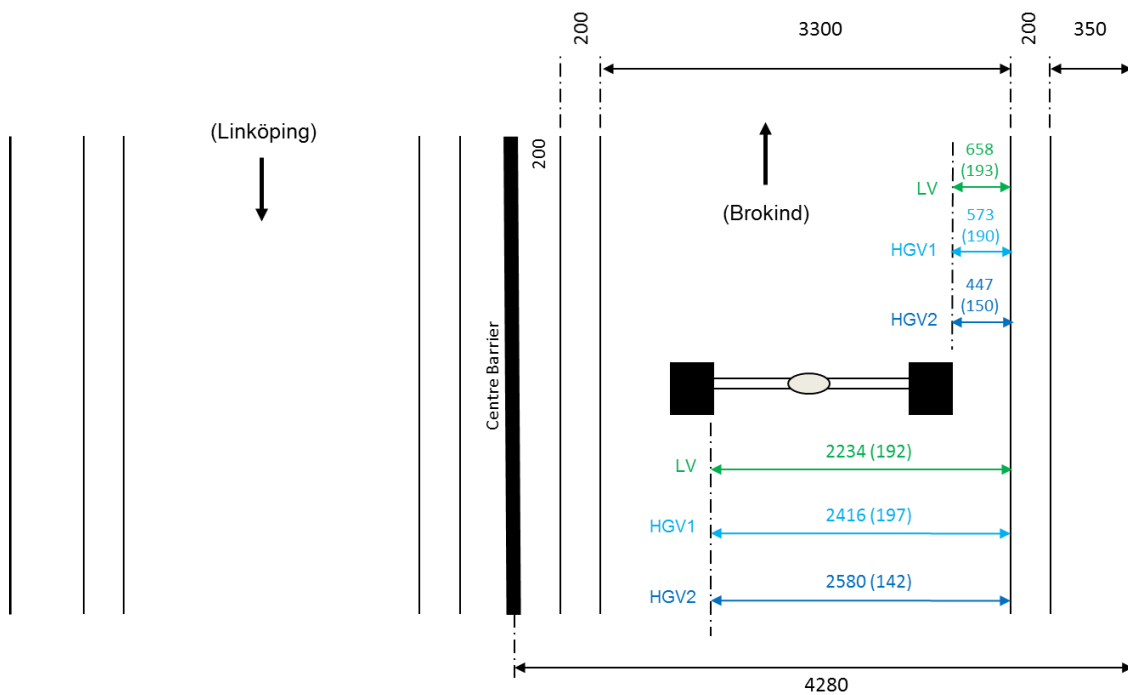


Figure 29. Ref 3a - Average Lateral Position and Standard Deviation.

Tyre tracking, assuming the following front tyre contact (with road surface) widths:

- light vehicles – 205 size = 175 mm surface contact width,
- HGV Group 1 – 295 size = 265 mm surface contact width, and
- HGV Group 2 – 385 size = 355 mm contact surface width.

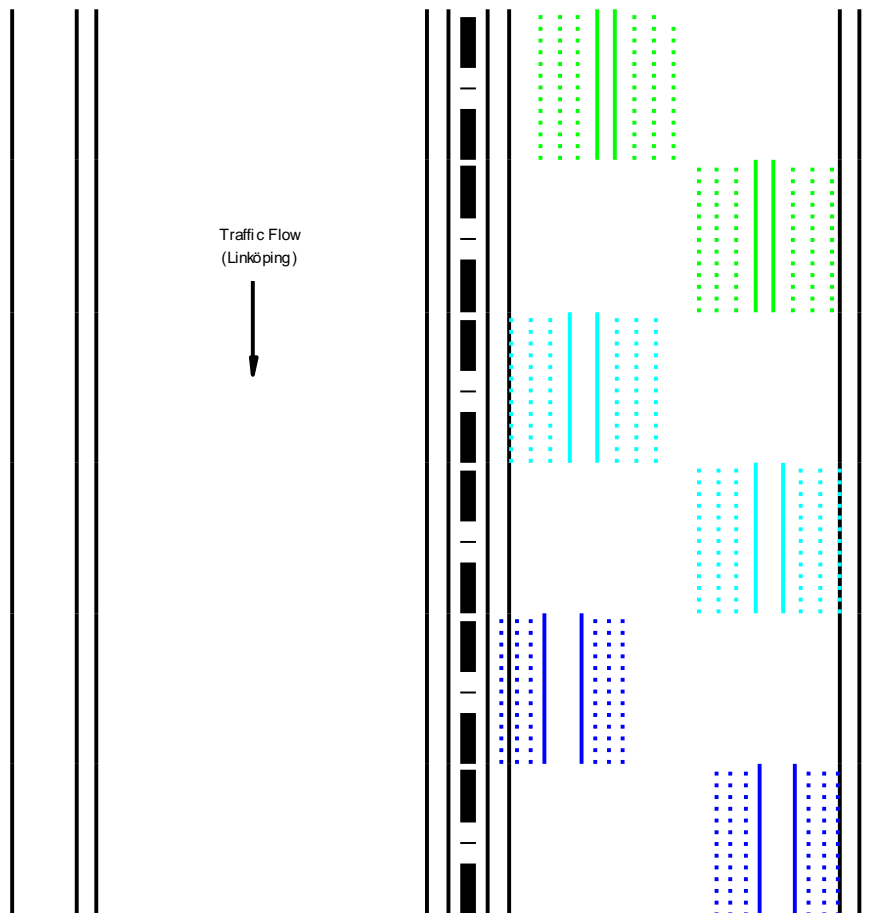


Figure 30. Ref 3a – Tyre Tracking.



Photograph 7. Ref 31. (Photo. Terence McGarvey).

Ref 3b: Road 23/34, Skeda Udde, National Route, Barrier Separated (1+1)

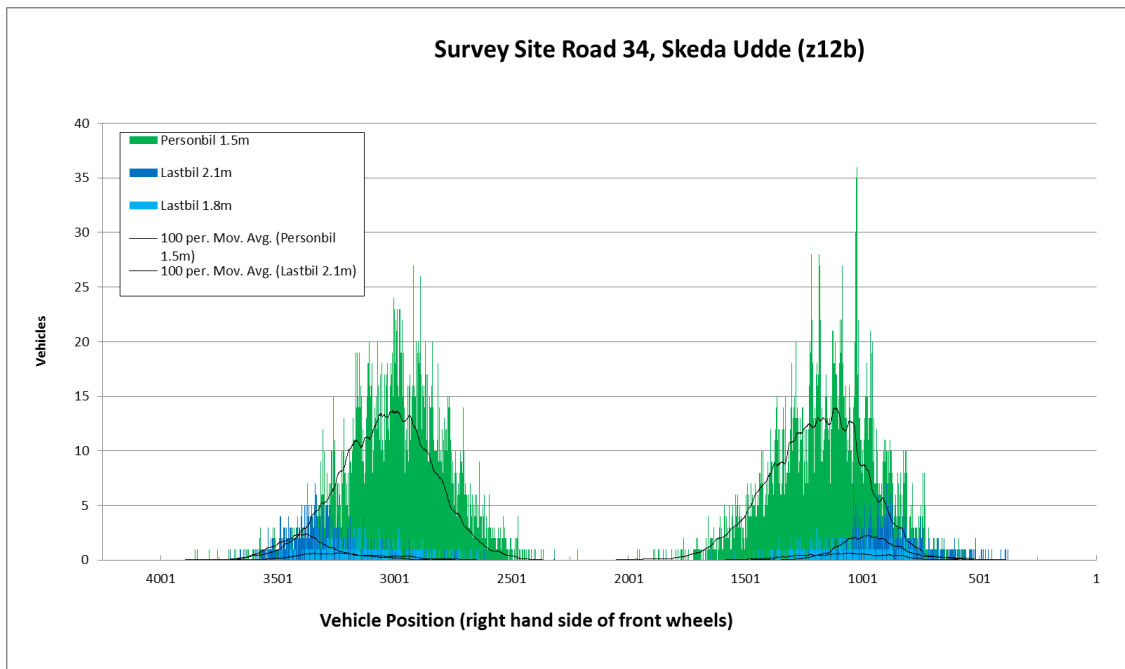


Figure 31. Ref 3b – Distribution of Lateral Position.

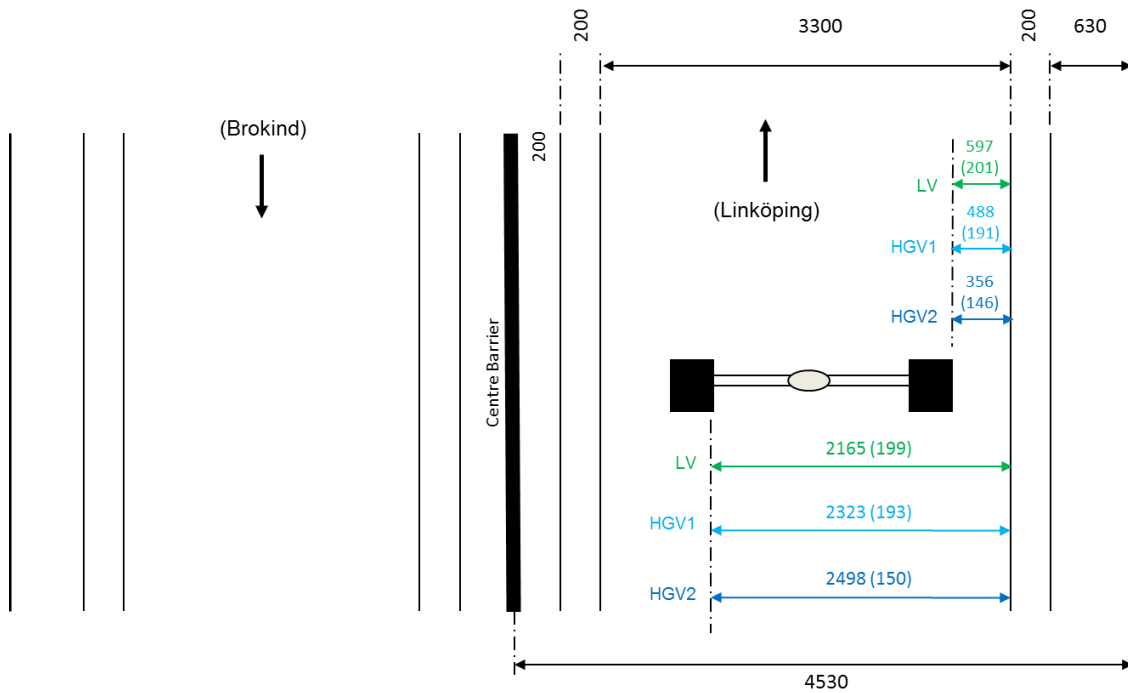


Figure 32. Ref 3b - Average Lateral Position and Standard Deviation.

Tyre tracking, assuming the following front tyre contact (with road surface) widths:

- light vehicles – 205 size = 175 mm surface contact width,
- HGV Group 1 – 295 size = 265 mm surface contact width, and
- HGV Group 2 – 385 size = 355 mm contact surface width.

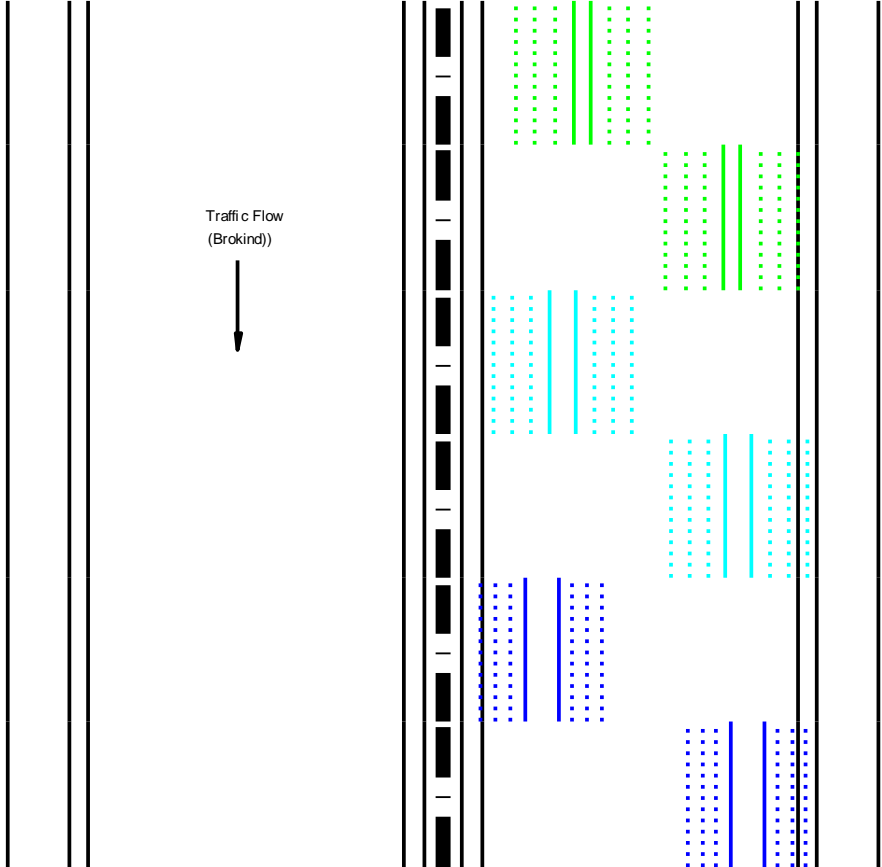


Figure 33. Ref 3b – Tyre Tracking.



Photograph 8. Ref 3b. (Photo. Terence McGarvey).

Ref 4: E6, Uddevalla, European Route, Motorway

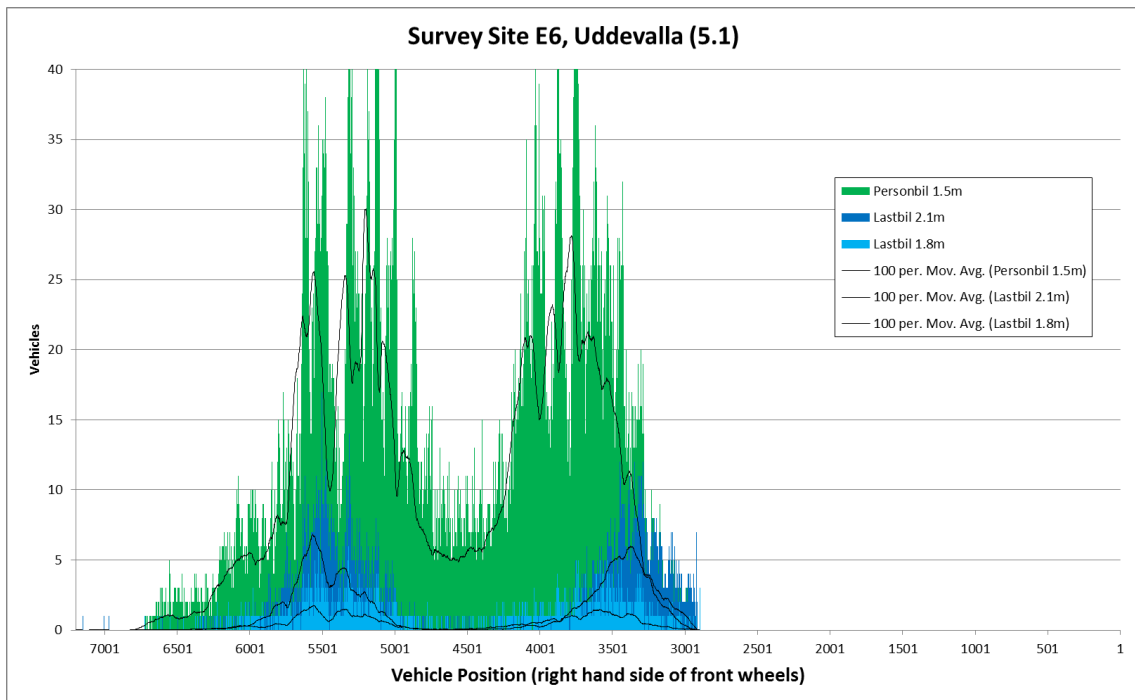


Figure 34. Ref 4 Distribution of Lateral Position.

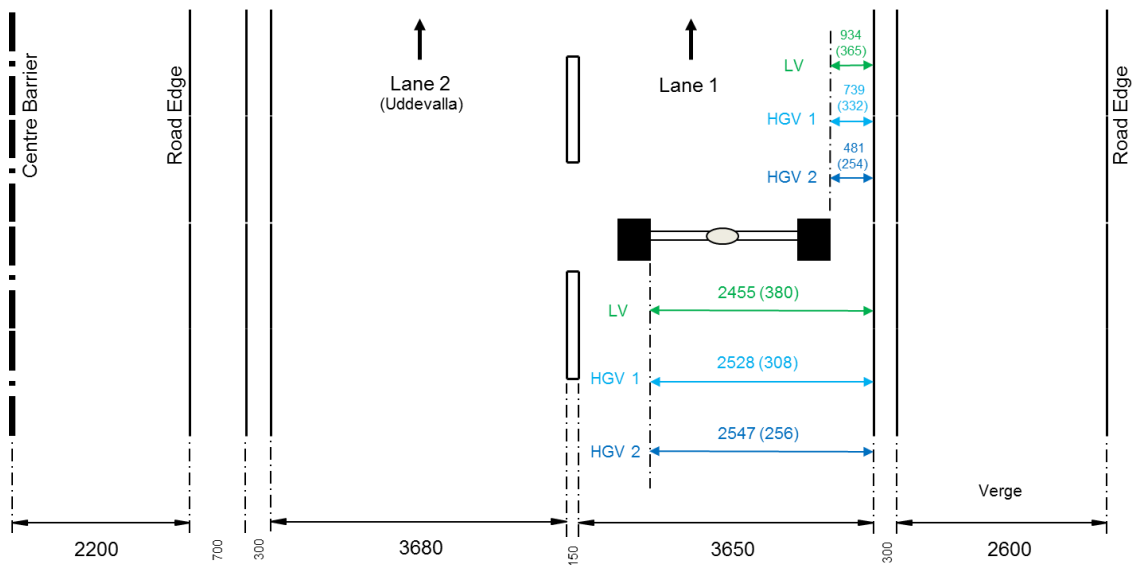


Figure 35. Ref 4 - Average Lateral Position and Standard Deviation.

Tyre tracking, assuming the following front tyre contact (with road surface) widths:

- light vehicles – 205 size = 175 mm surface contact width,
- HGV Group 1 – 295 size = 265 mm surface contact width, and
- HGV Group 2 – 385 size = 355 mm contact surface width.

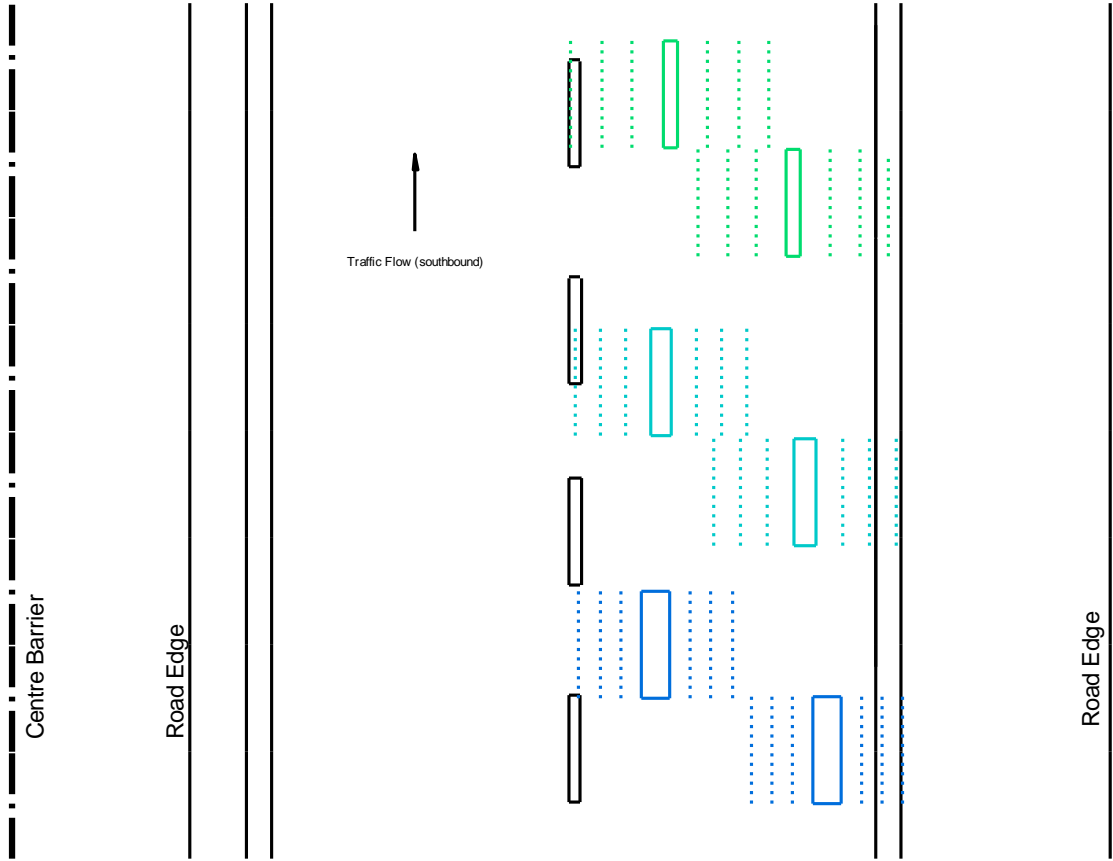


Figure 36. Ref 4 – Tyre Tracking.



Photograph 9. Ref 4. (Photo. Terence McGarvey).

Ref 5a: E4, Linköping, European Route, Motorway

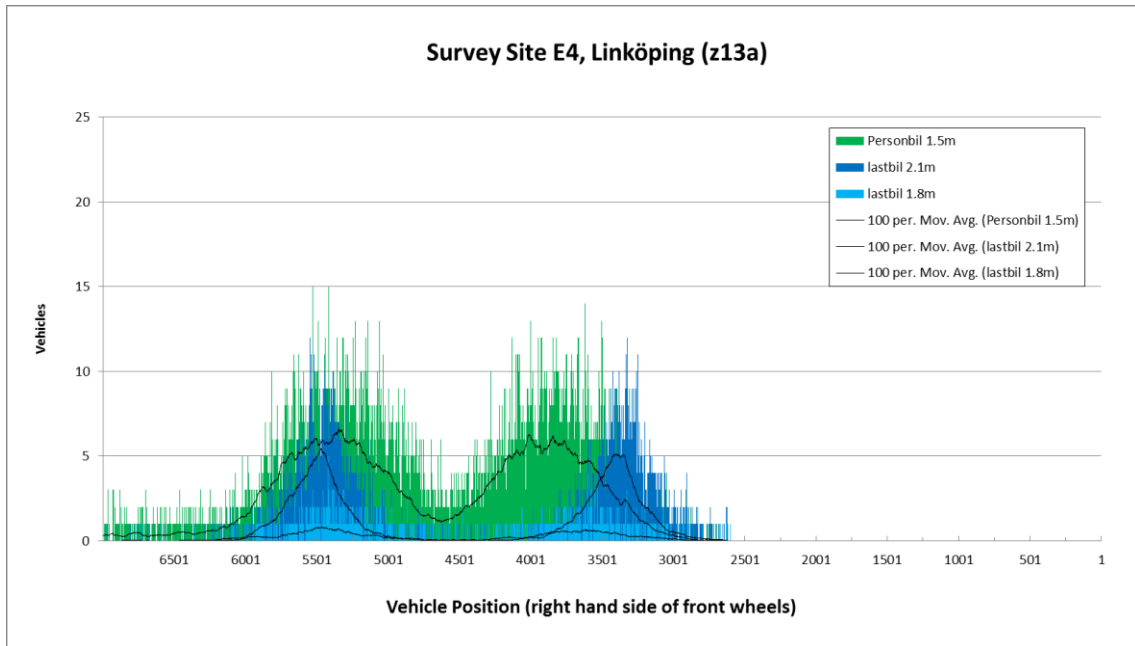


Figure 37. Ref 5a – Distribution of Lateral Position.

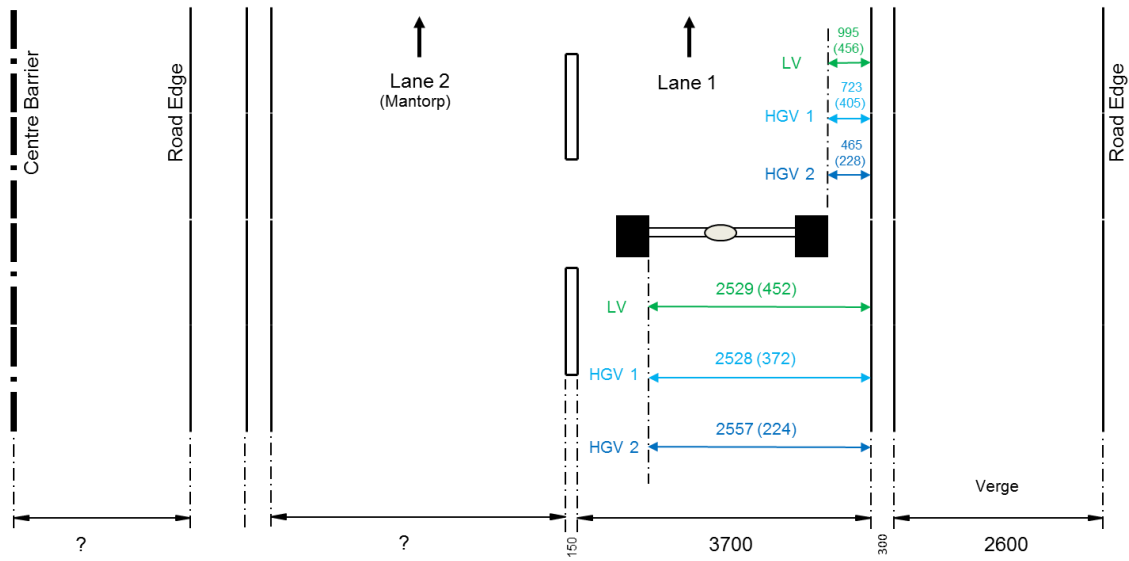


Figure 38. Ref 5a - Average Lateral Position and Standard Deviation.

Tyre tracking, assuming the following front tyre contact (with road surface) widths:

- light vehicles – 205 size = 175 mm surface contact width,
- HGV Group 1 – 295 size = 265 mm surface contact width, and
- HGV Group 2 – 385 size = 355 mm contact surface width.

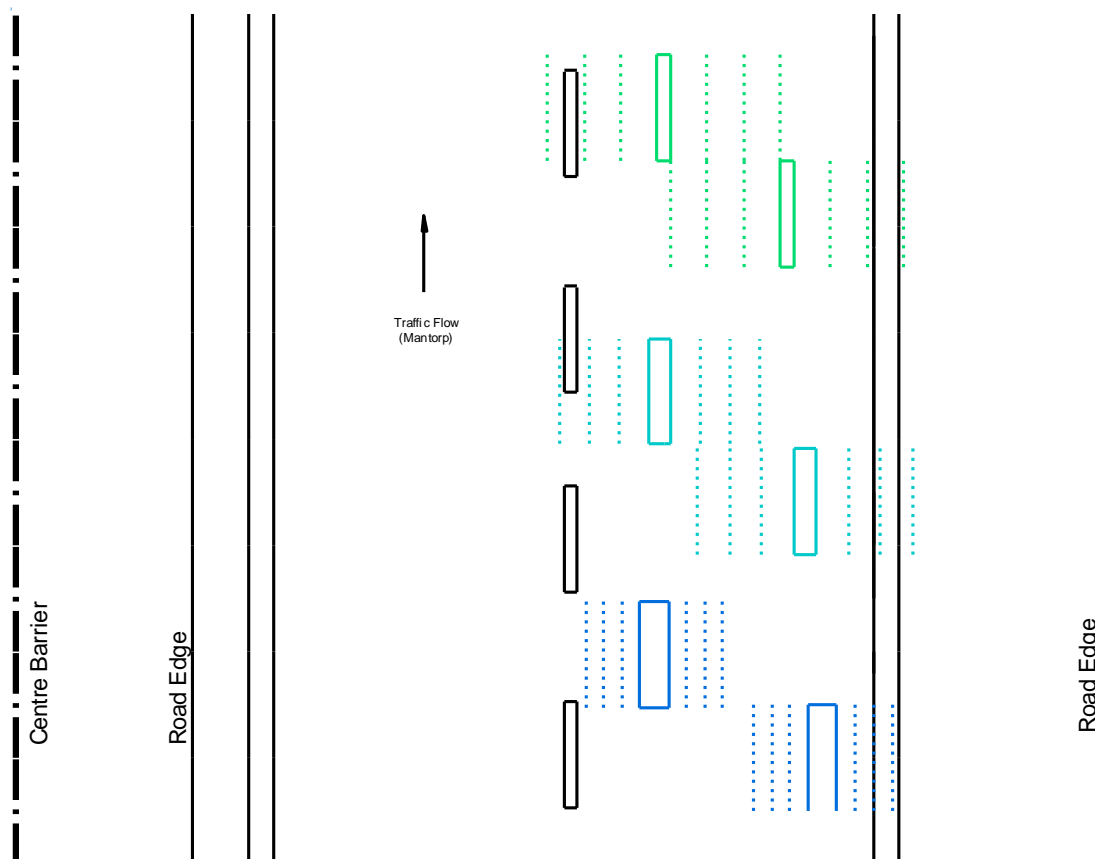
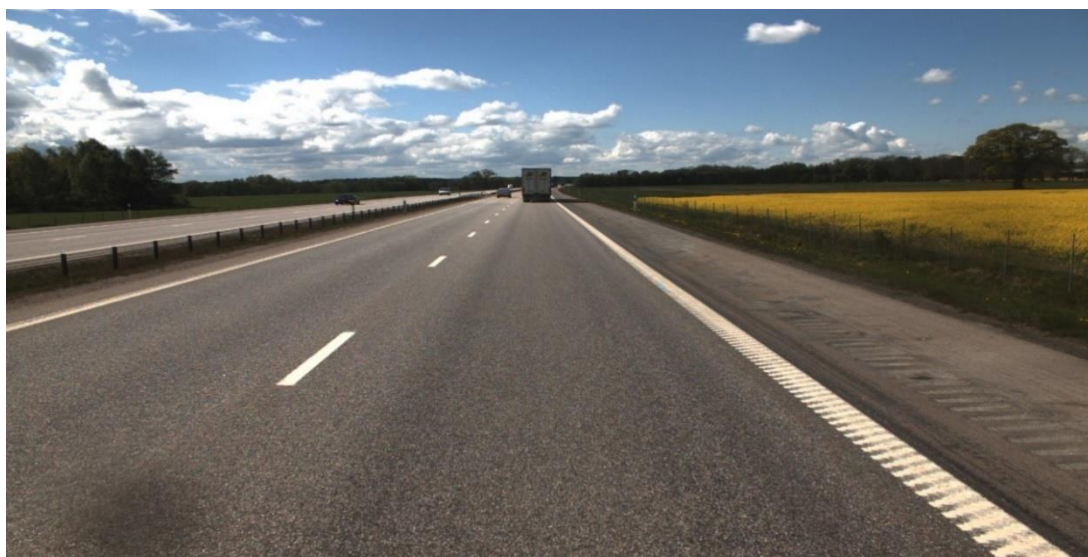


Figure 39. Ref 5a - Tyre Tracking.



Photograph 10. Ref 5a. (Photo. Trafikverket PMSv3).

Ref 5b: E4, Linköping, European Route, Motorway

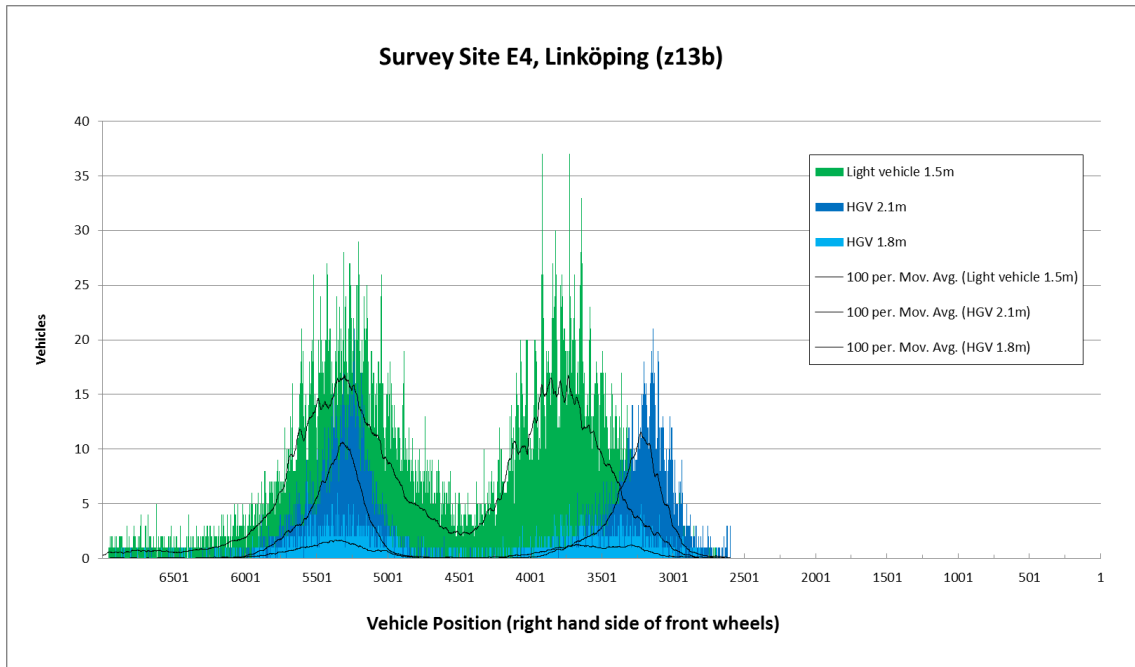


Figure 40. Ref 5b – Distribution of Lateral Position.

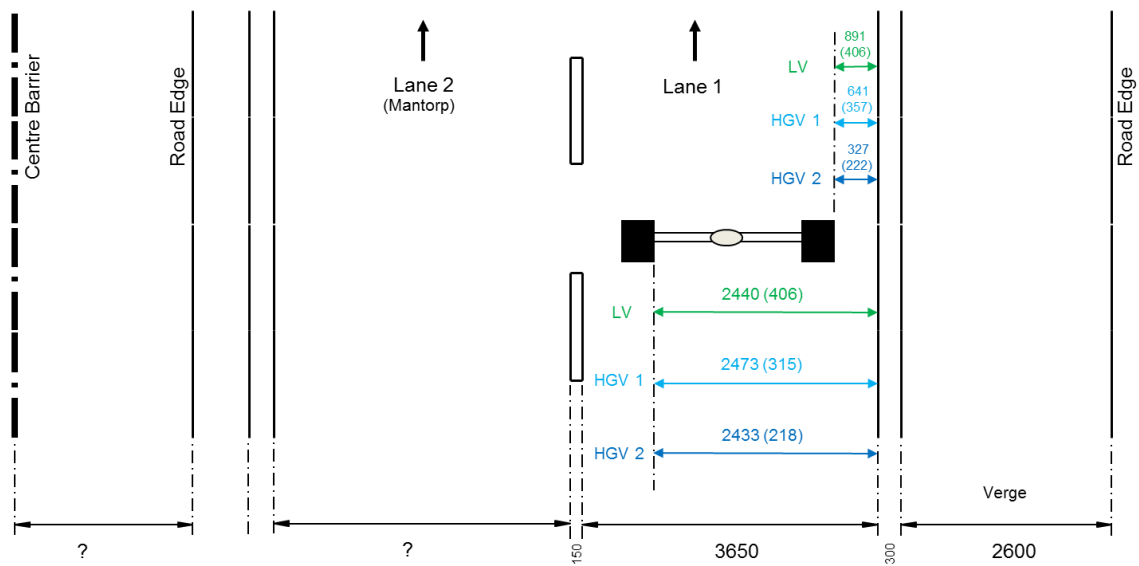


Figure 41. Ref 5b - Average Lateral Position and Standard Deviation.

Tyre tracking, assuming the following front tyre contact (with road surface) widths:

- light vehicles – 205 size = 175 mm surface contact width,
- HGV Group 1 – 295 size = 265 mm surface contact width, and
- HGV Group 2 – 385 size = 355 mm contact surface width.

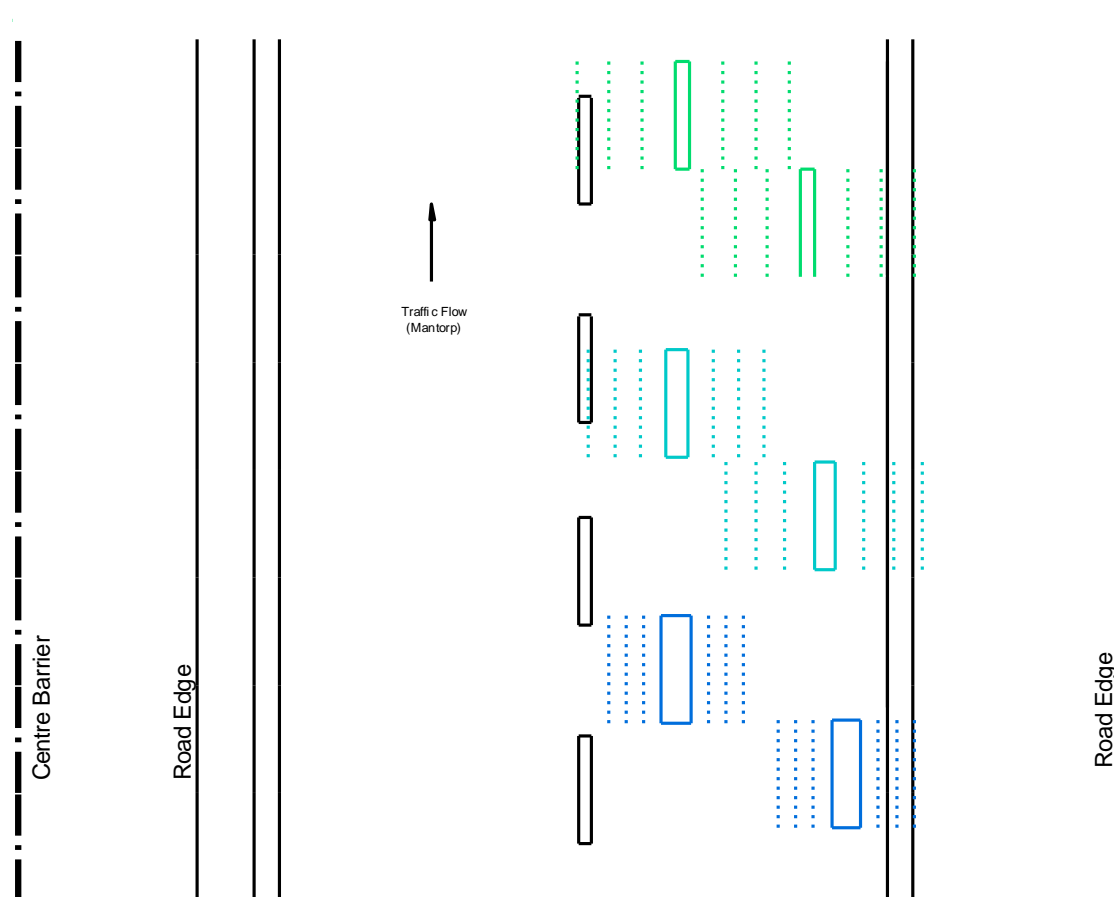


Figure 42. Ref 5b - Tyre Tracking.



Photograph 11. Ref 5b. (Photo. Trafikverket PMSv3).

Ref 6a: Road 50, Mjölby, National Route, Four Lane

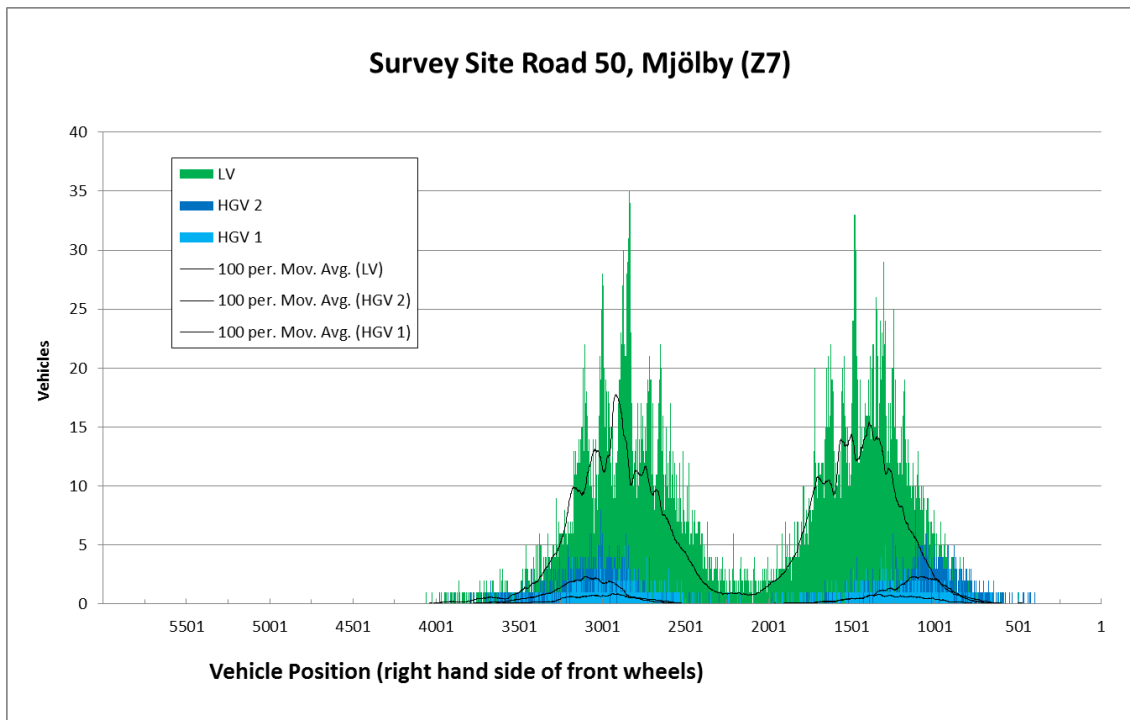


Figure 43. Ref 6a – Distribution of Lateral Position.

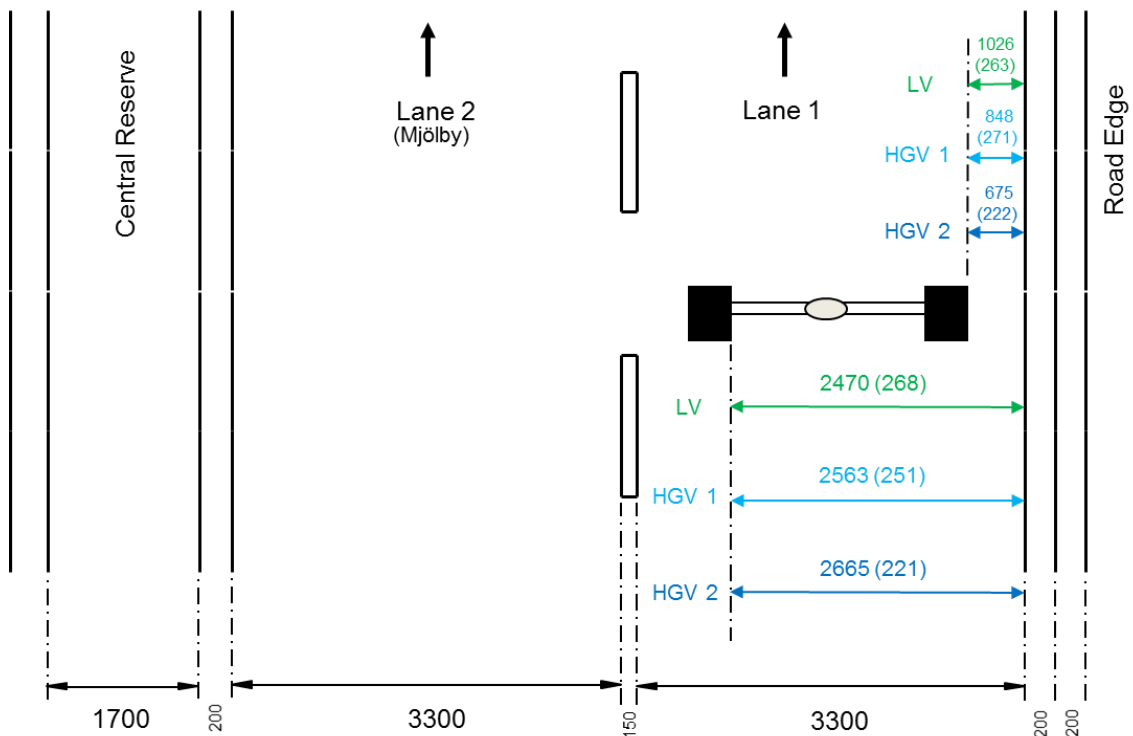


Figure 44. Ref 6a - Average Lateral Position and Standard Deviation.

Tyre tracking, assuming the following front tyre contact (with road surface) widths:

- light vehicles – 205 size = 175 mm surface contact width,
- HGV Group 1 – 295 size = 265 mm surface contact width, and
- HGV Group 2 – 385 size = 355 mm contact surface width.

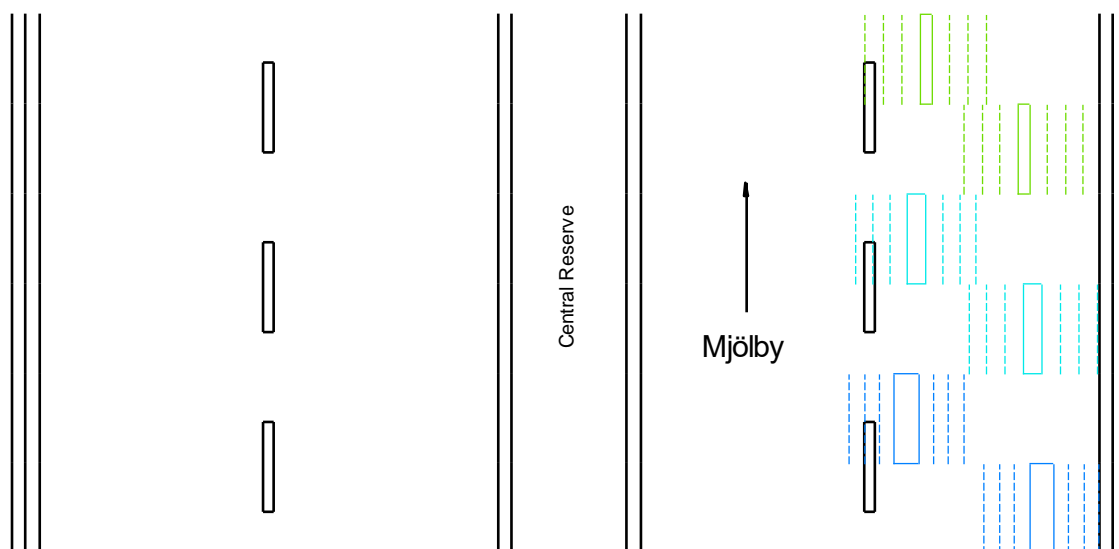


Figure 45. Ref 6a – Tyre Tracking.



Photograph 12. Ref 6a. (Photo. Terence McGarvey).

Ref 6b: Road 50, Mjölby, National Route, Four Lane

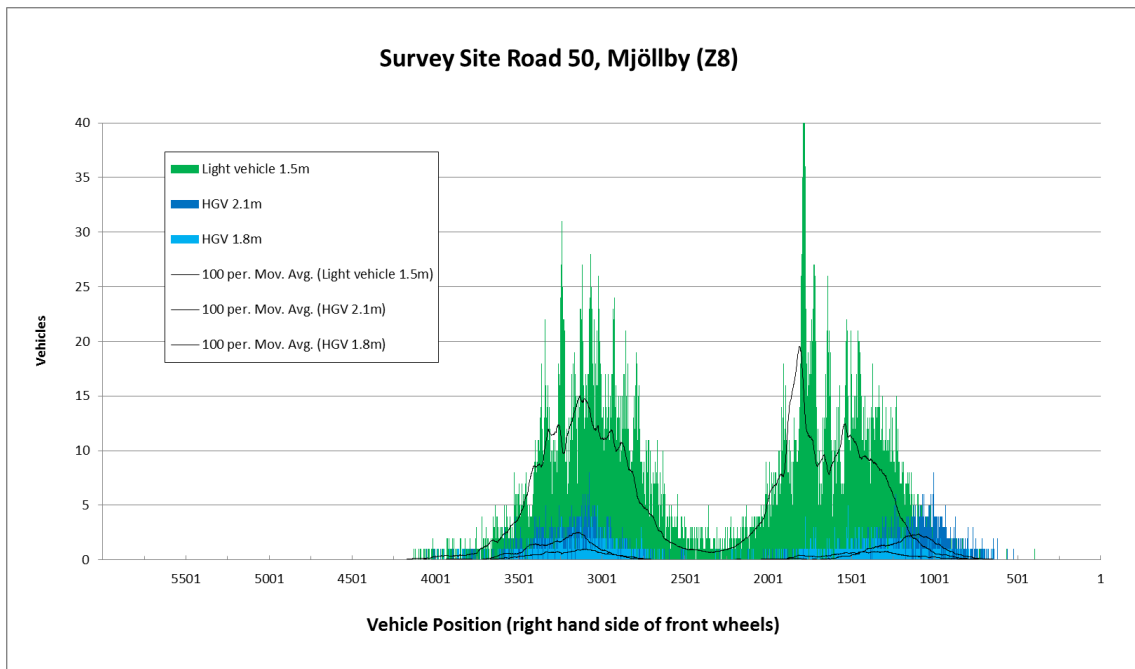


Figure 46. Ref 6b – Distribution of Lateral Position.

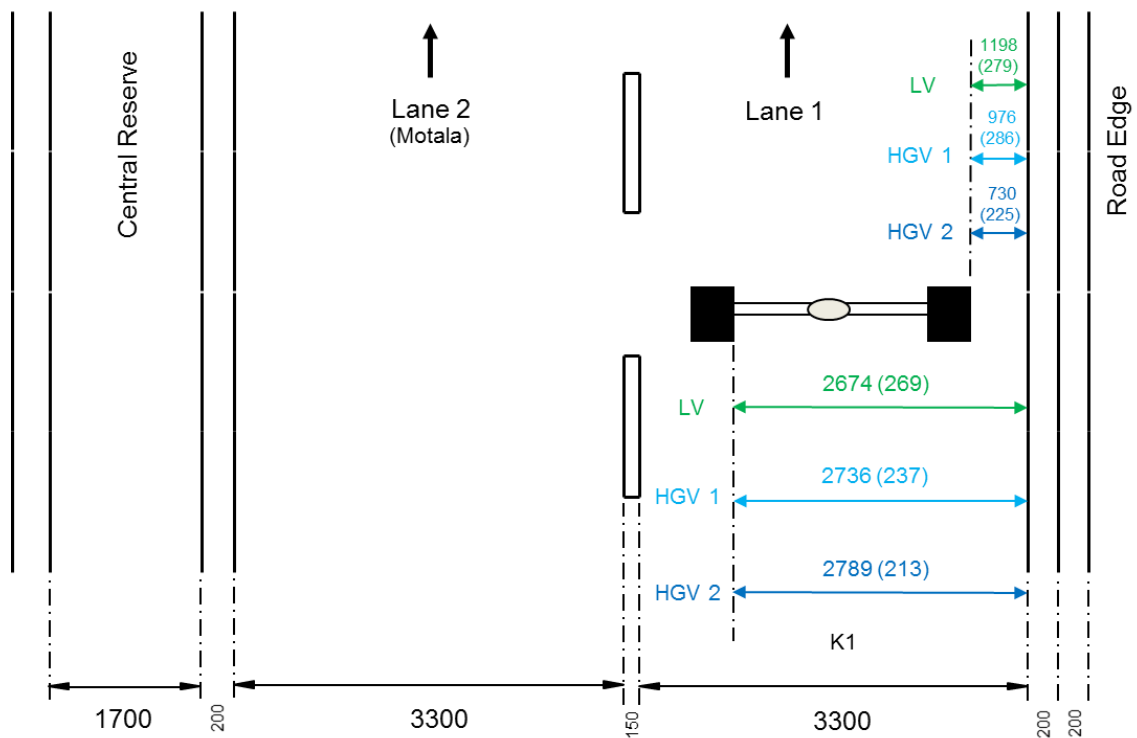


Figure 47. Ref 6b - Average Lateral Position and Standard Deviation.

Tyre tracking, assuming the following front tyre contact (with road surface) widths:

- light vehicles – 205 size = 175 mm surface contact width,
- HGV Group 1 – 295 size = 265 mm surface contact width, and
- HGV Group 2 – 385 size = 355 mm contact surface width.

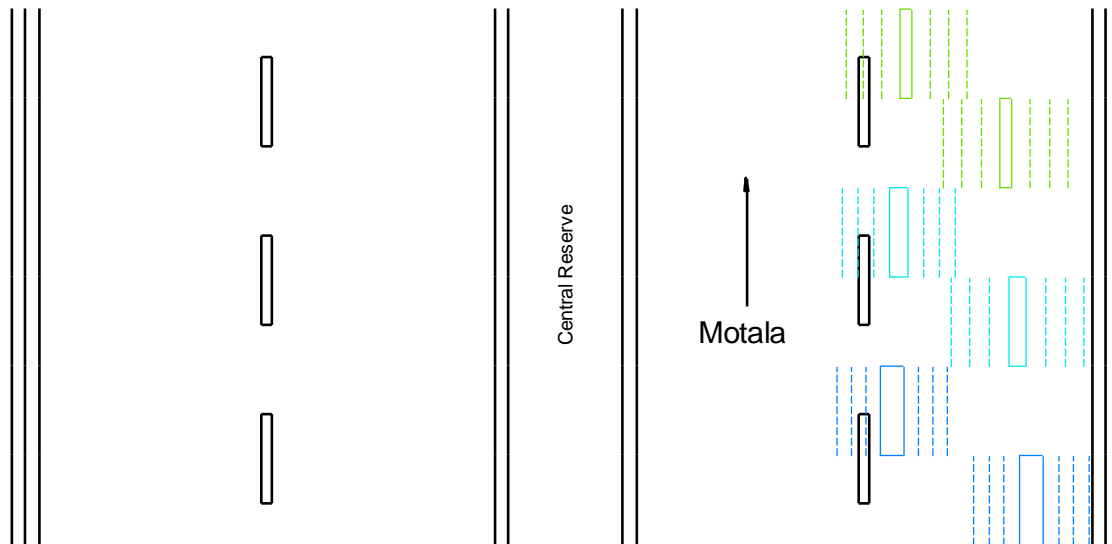


Figure 48. Ref 6b – Tyre Tracking.



Photograph 13. Ref 6b. (Photo. Terence McGarvey).

Ref 7a: Road 796, Gistad, Secondary Rural Road, Standard (13.35 m)

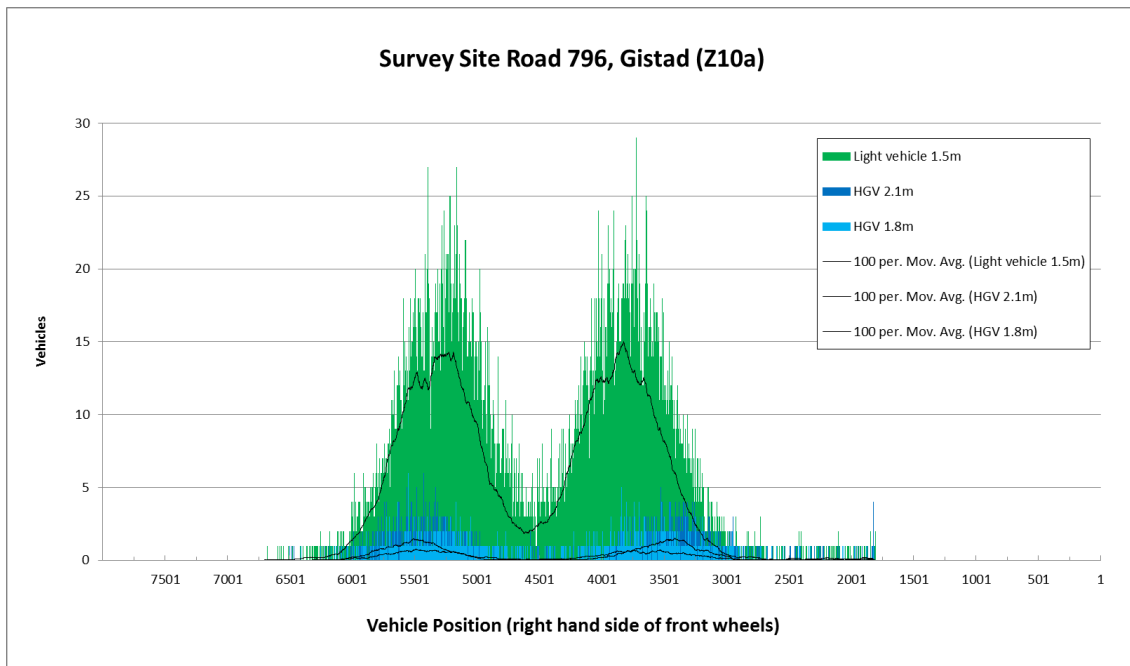


Figure 49. Ref 7a - Distribution of Lateral Position.

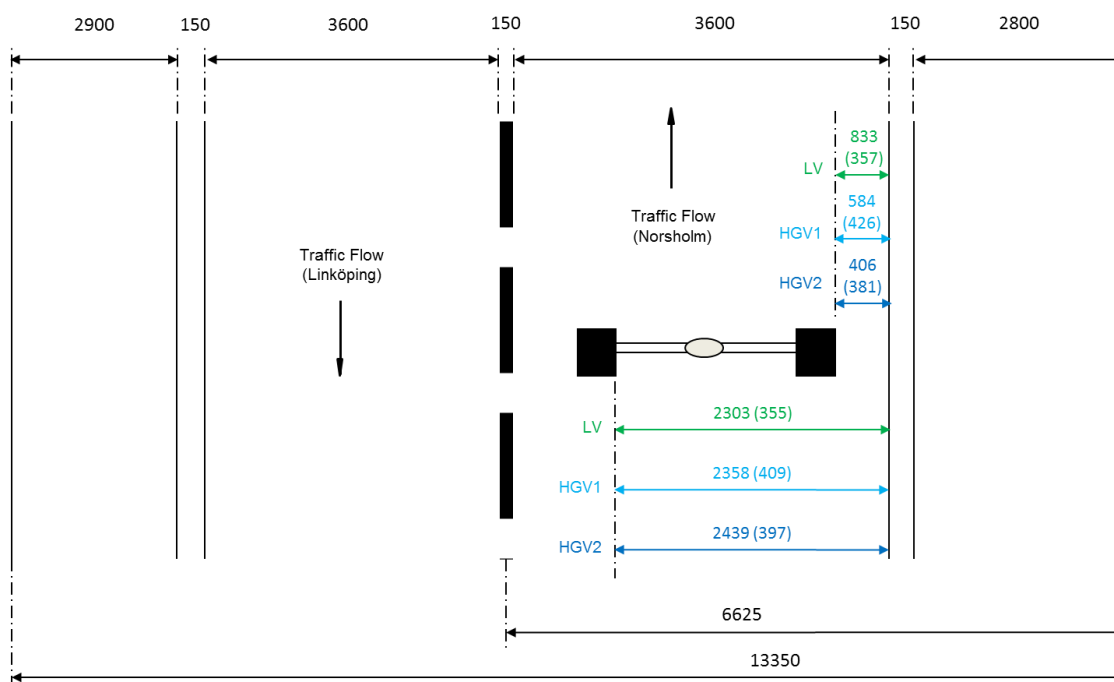


Figure 50. Ref 7a - Average Lateral Position and Standard Deviation.

Tyre tracking, assuming the following front tyre contact (with road surface) widths:

- light vehicles – 205 size = 175 mm surface contact width,
- HGV Group 1 – 295 size = 265 mm surface contact width, and
- HGV Group 2 – 385 size = 355 mm contact surface width.

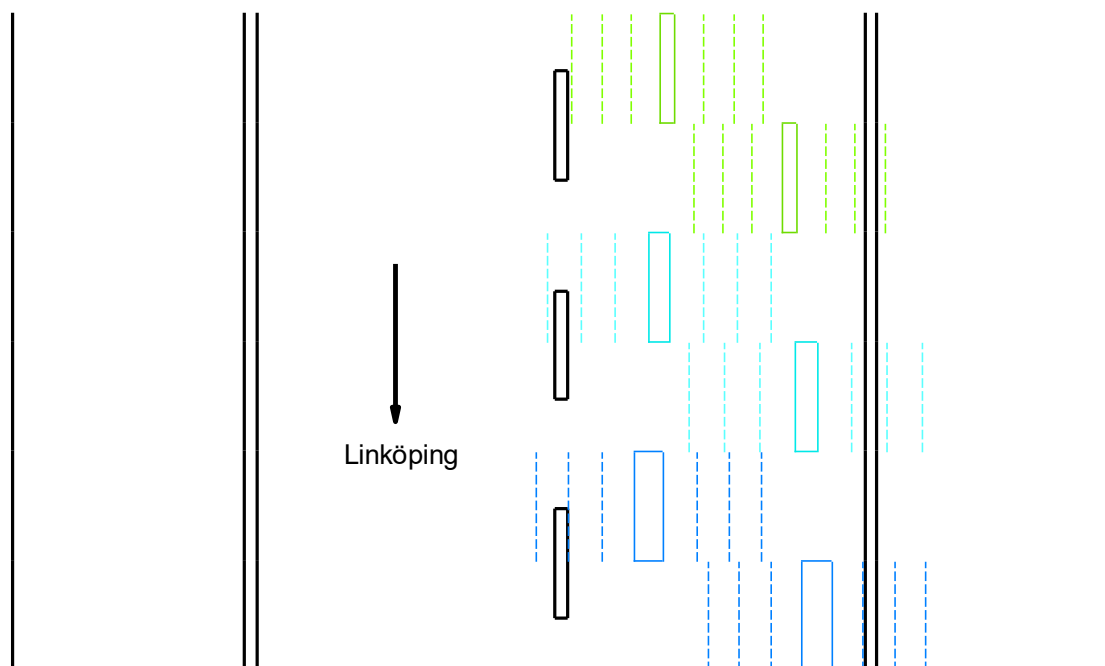


Figure 51. Ref 7a – Tyre Tracking.



Photograph 14. Ref 7a. (Photo. Terence McGarvey).

Ref 7b: Road 796, Gistad, Secondary Rural Road, Standard (13.35 m)

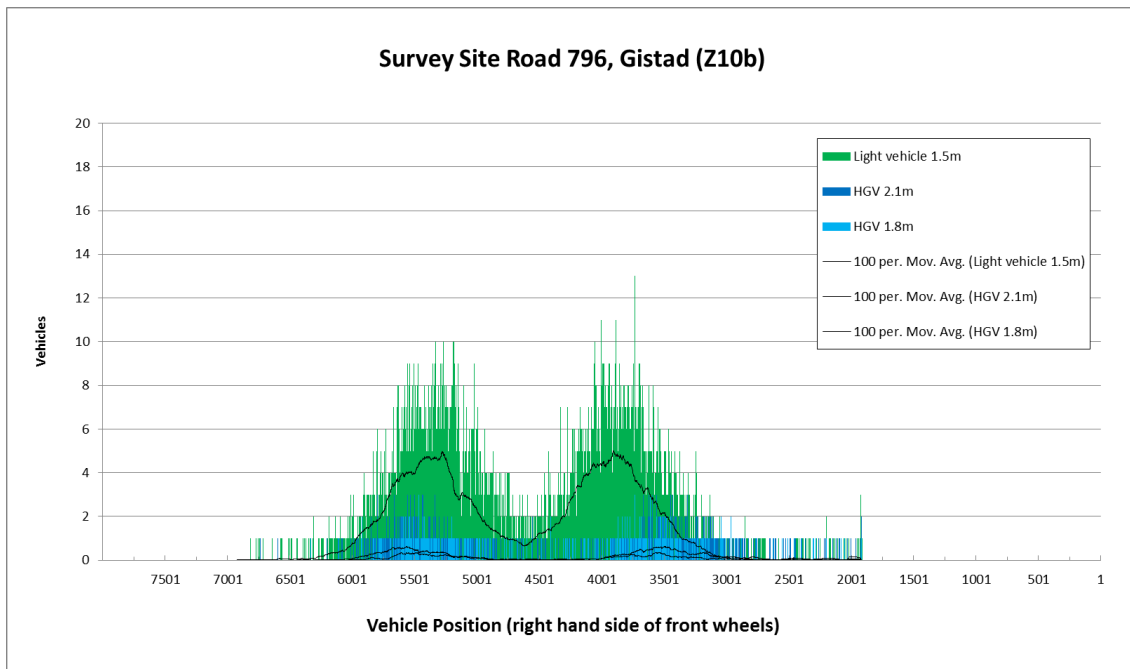


Figure 52. Ref 7b – Distribution of Lateral Position.

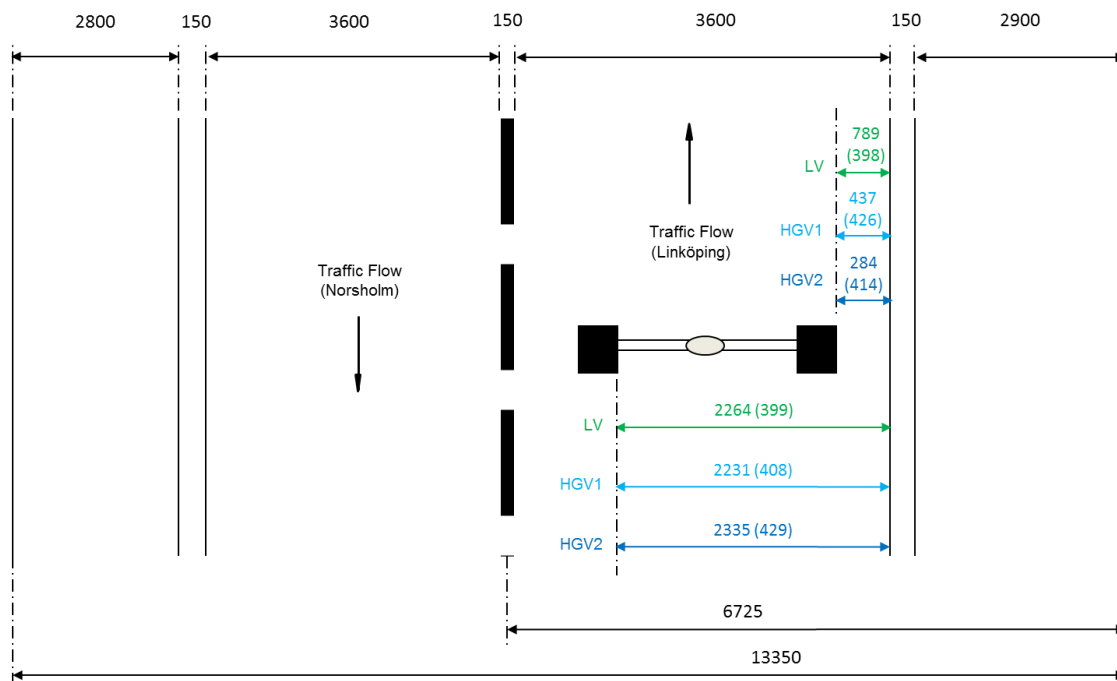


Figure 53. Ref 7b - Average Lateral Position and Standard Deviation.

Tyre tracking, assuming the following front tyre contact (with road surface) widths:

- light vehicles – 205 size = 175 mm surface contact width,
- HGV Group 1 – 295 size = 265 mm surface contact width, and
- HGV Group 2 – 385 size = 355 mm contact surface width.

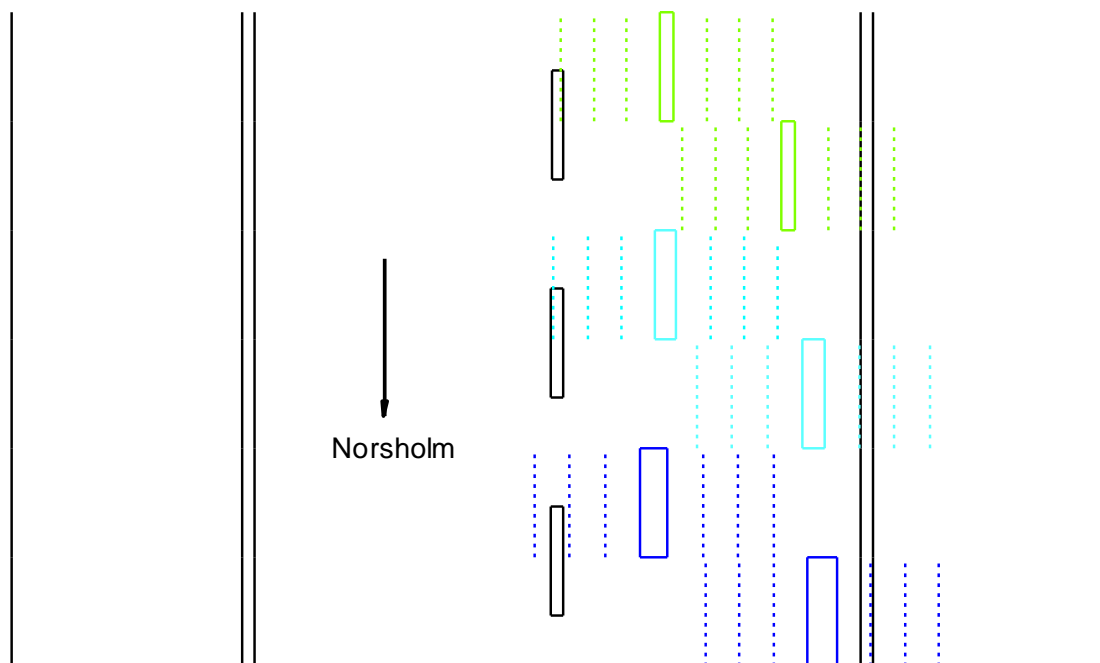


Figure 54. Ref 7b – Tyre Tracking.



Photograph 15. Ref 7b. (Photo. Terence McGarvey).

Ref 8: Bergsvägen, Berg, Secondary Rural Road, Standard (9.4 m)

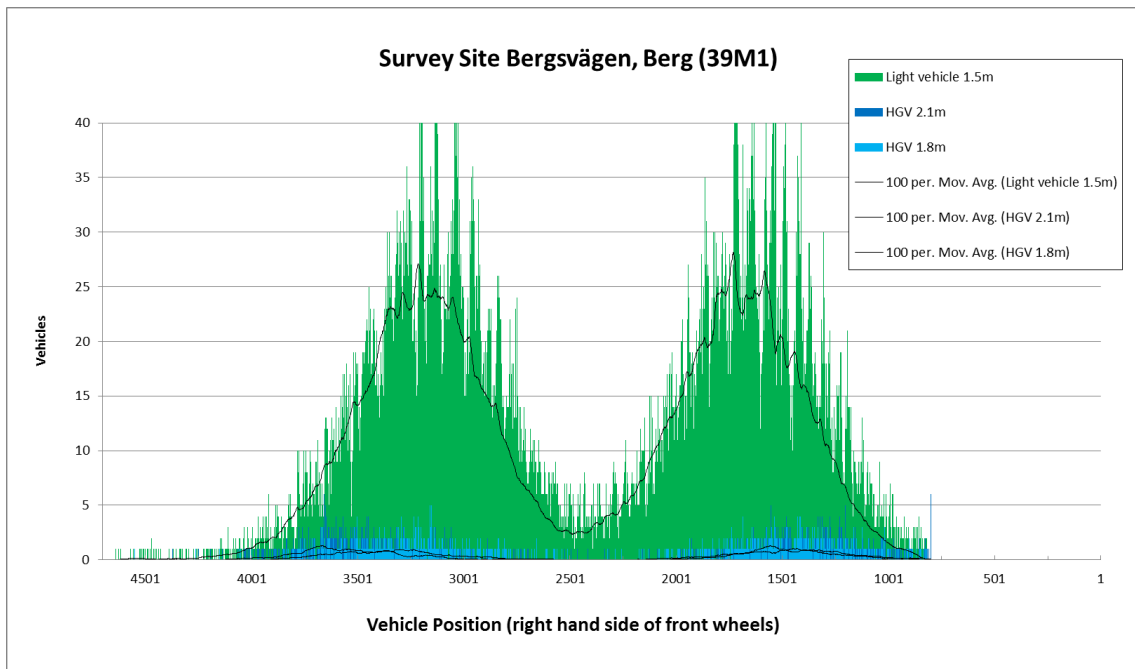


Figure 55. Ref 8 – Distribution of Lateral Position.

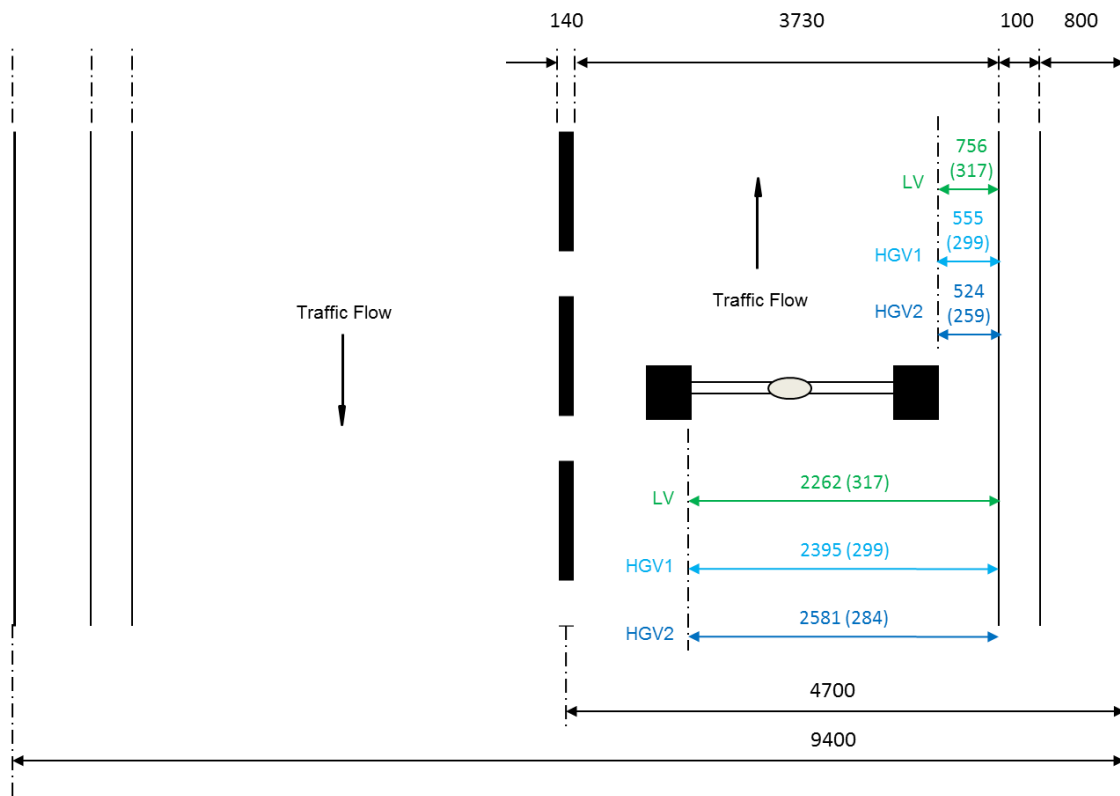


Figure 56. Ref 8 - Average Lateral Position and Standard Deviation.

Tyre tracking, assuming the following front tyre contact (with road surface) widths:

- light vehicles – 205 size = 175 mm surface contact width,
- HGV Group 1 – 295 size = 265 mm surface contact width, and
- HGV Group 2 – 385 size = 355 mm contact surface width.

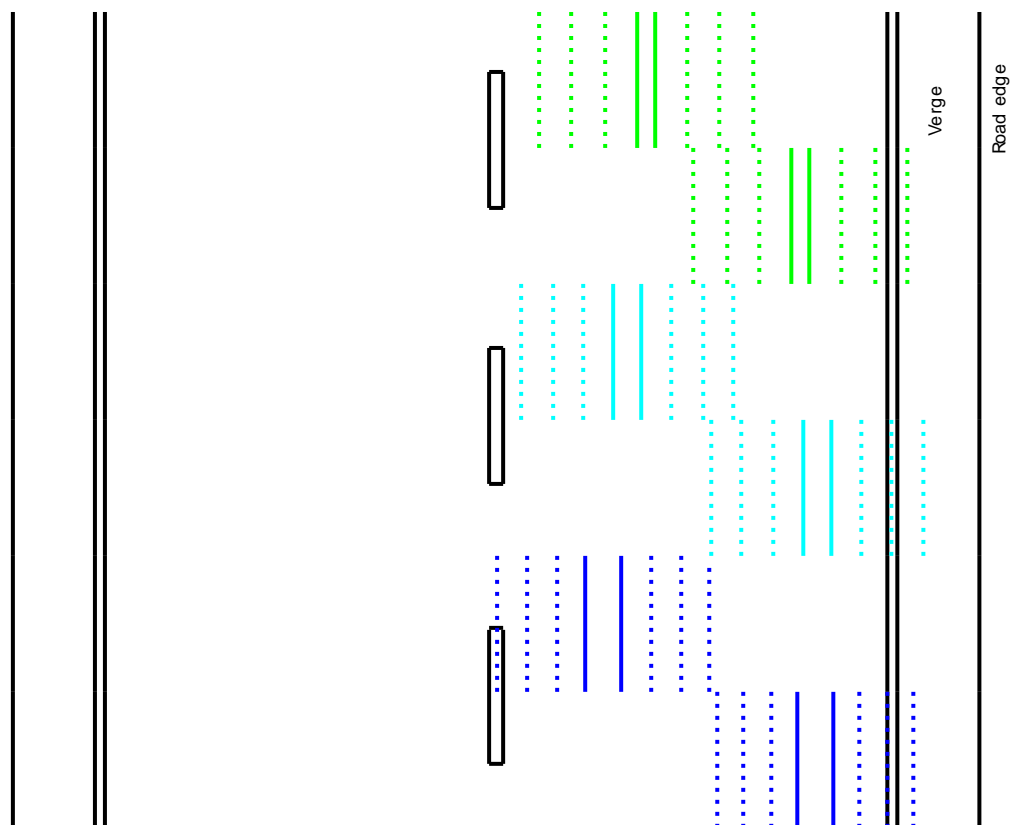


Figure 57. Ref 8 - Tyre Tracking.



Photograph 16. Ref 8. (Photo. Håkan Wilhelmsson).

Ref 9: Road 19, Tomelilla, National Route, Standard (9.2 m)

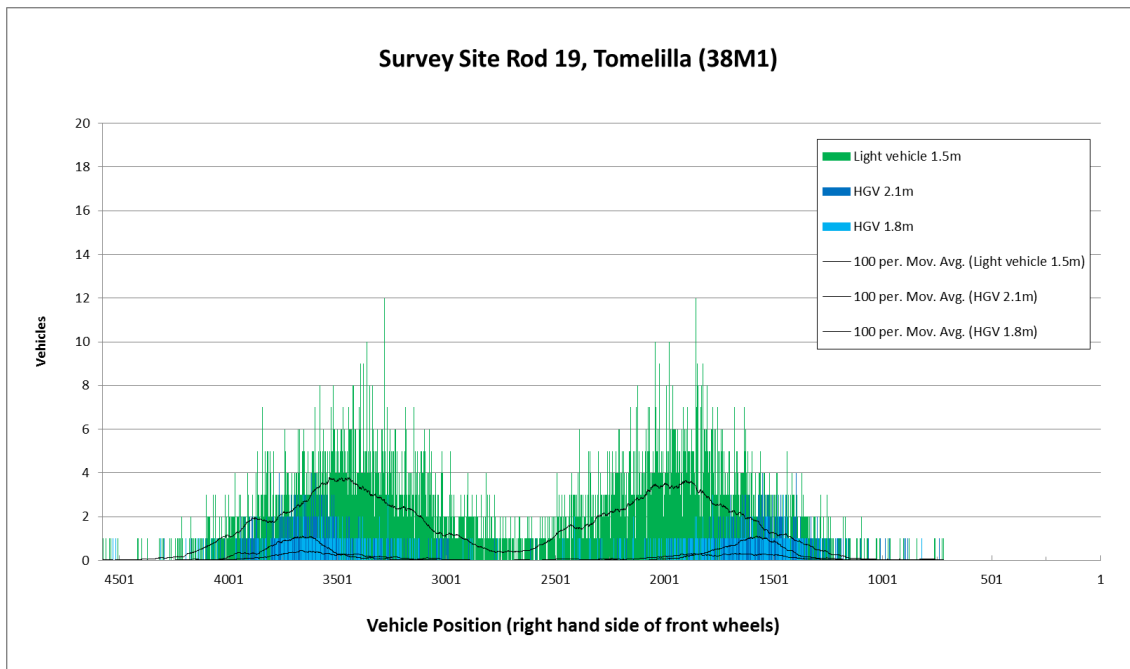


Figure 58. Ref 9 – Distribution of Lateral Position.

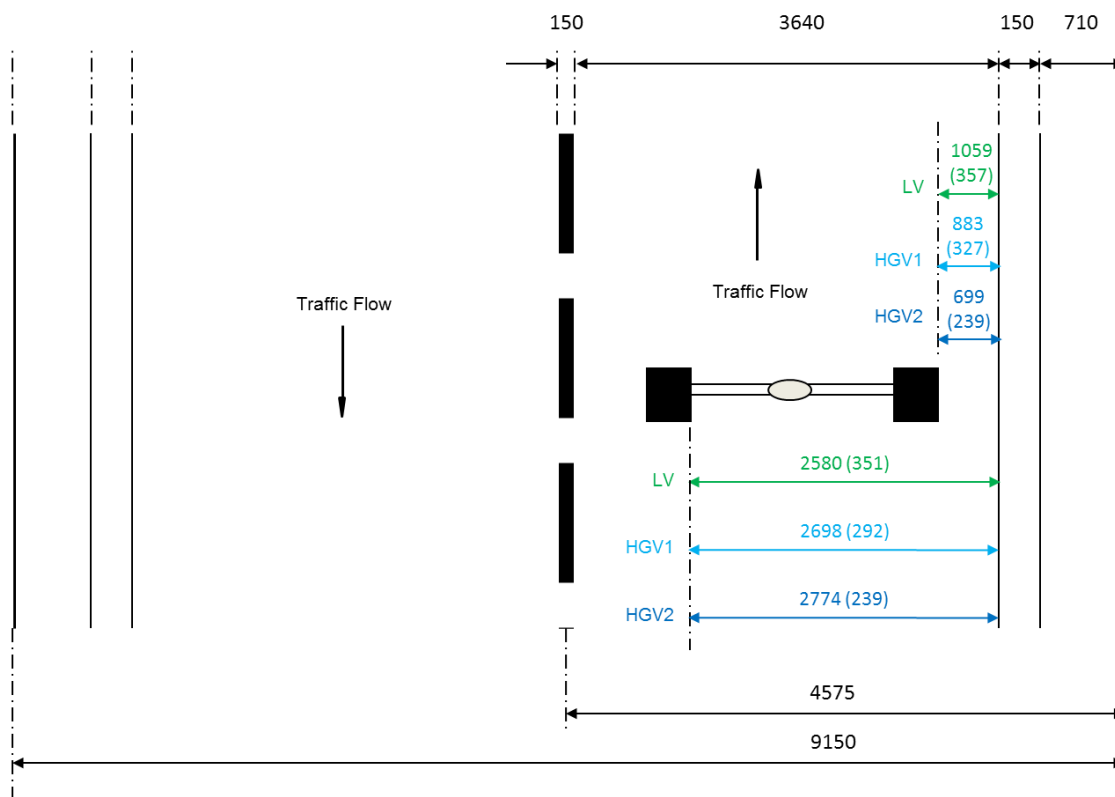


Figure 59. Ref 9 - Average Lateral Position and Standard Deviation.

Tyre tracking, assuming the following front tyre contact (with road surface) widths:

- light vehicles – 205 size = 175 mm surface contact width,
- HGV Group 1 – 295 size = 265 mm surface contact width, and
- HGV Group 2 – 385 size = 355 mm contact surface width.

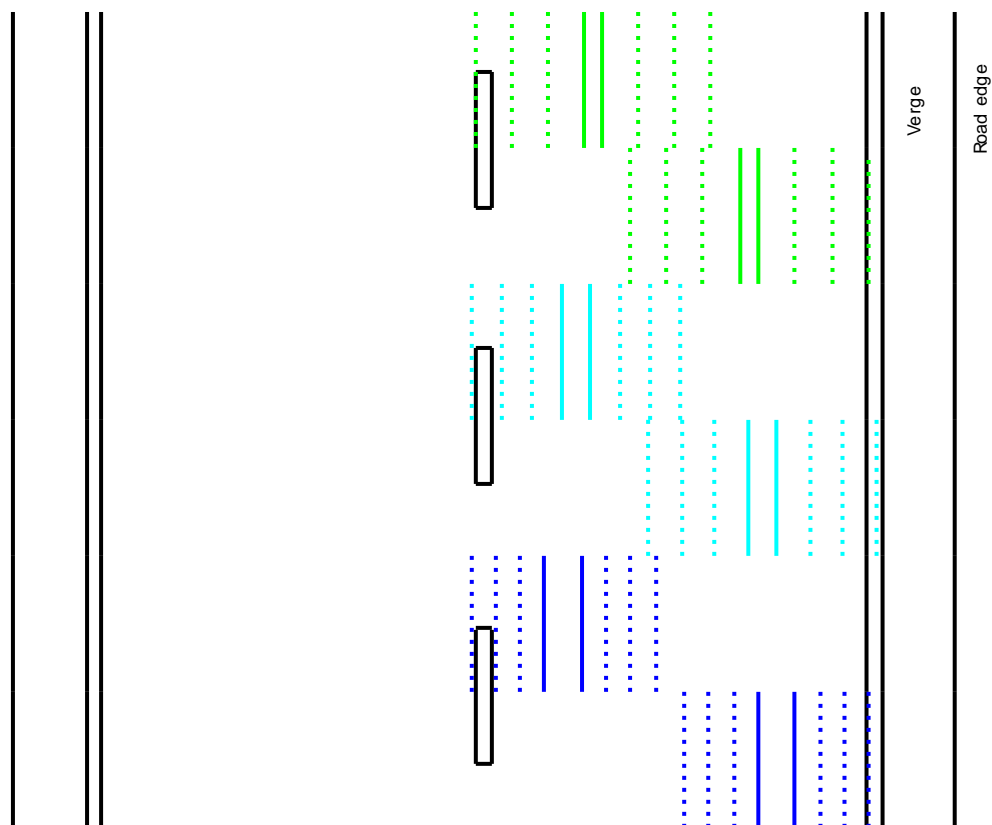


Figure 60. Ref 9 - Tyre Tracking.



Photograph 17. Ref 9. (Photo. Håkan Wilhelmsson).

Ref 10: Road 9/11, Simrishamn, National Route, Standard (9.0 m)

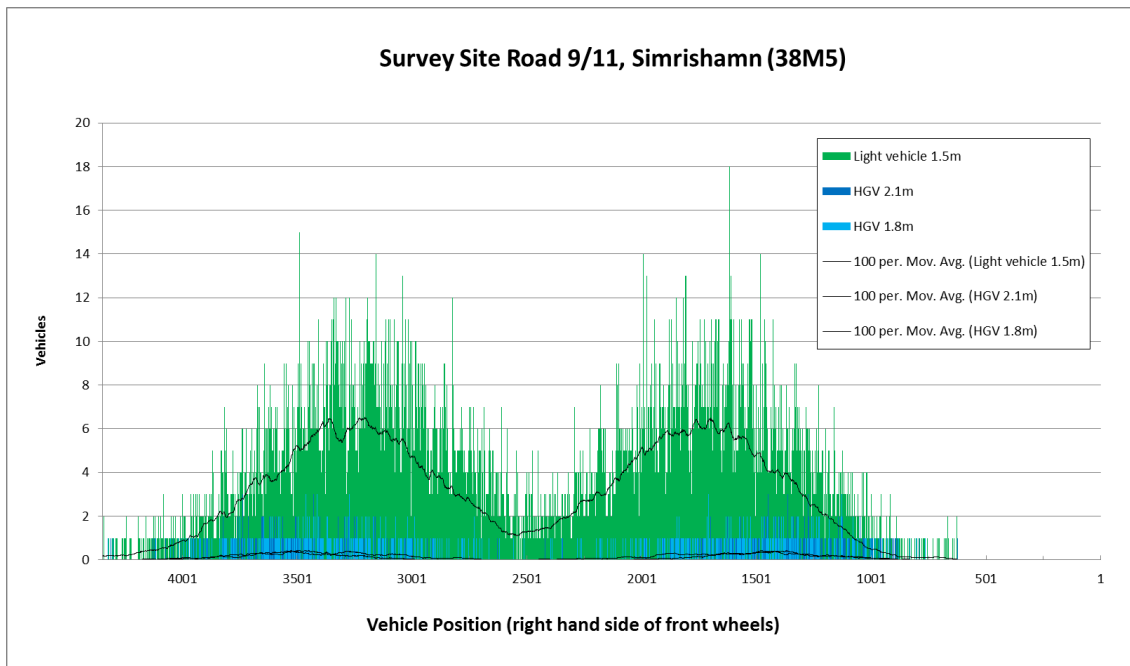


Figure 61. Ref 10 – Distribution of Lateral Position.

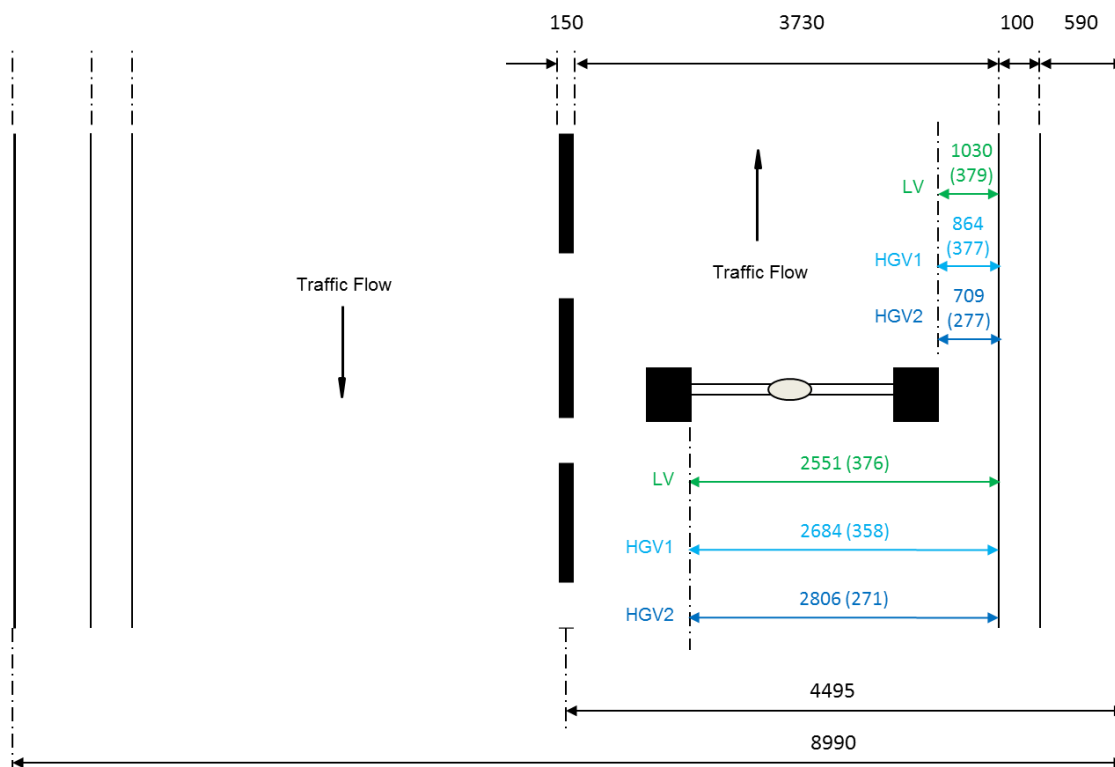


Figure 62. Ref 10 - Average Lateral Position and Standard Deviation.

Tyre tracking, assuming the following front tyre contact (with road surface) widths:

- light vehicles – 205 size = 175 mm surface contact width,
- HGV Group 1 – 295 size = 265 mm surface contact width, and
- HGV Group 2 – 385 size = 355 mm contact surface width.

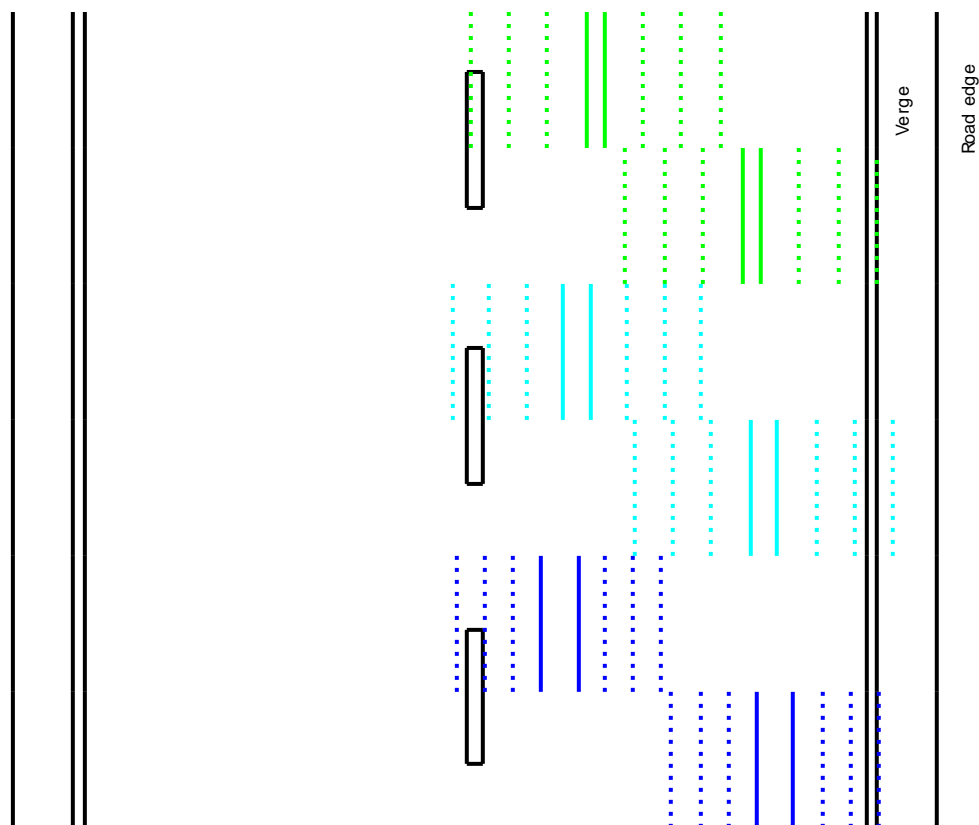


Figure 63. Ref 10 - Tyre Tracking.



Photograph 18. Ref 10. (Photo. Håkan Wilhelmsson).

Ref 11: Road 23/34, Brokind, National Route, Standard (8.8 m)

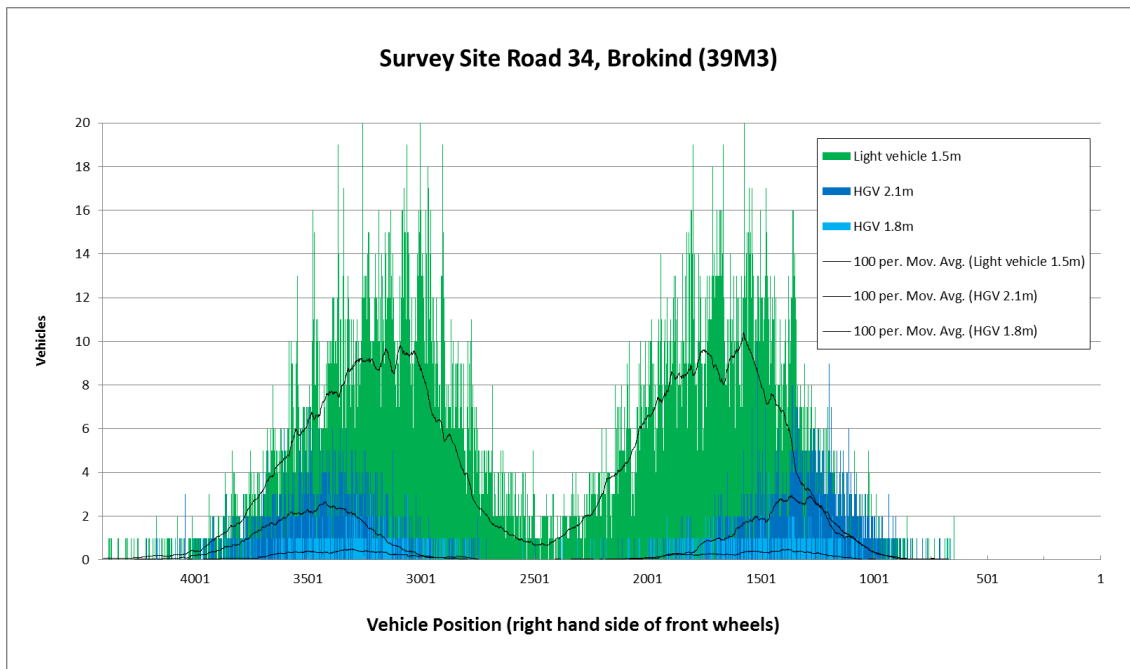


Figure 64. Ref 11 – Distribution of Lateral Position.

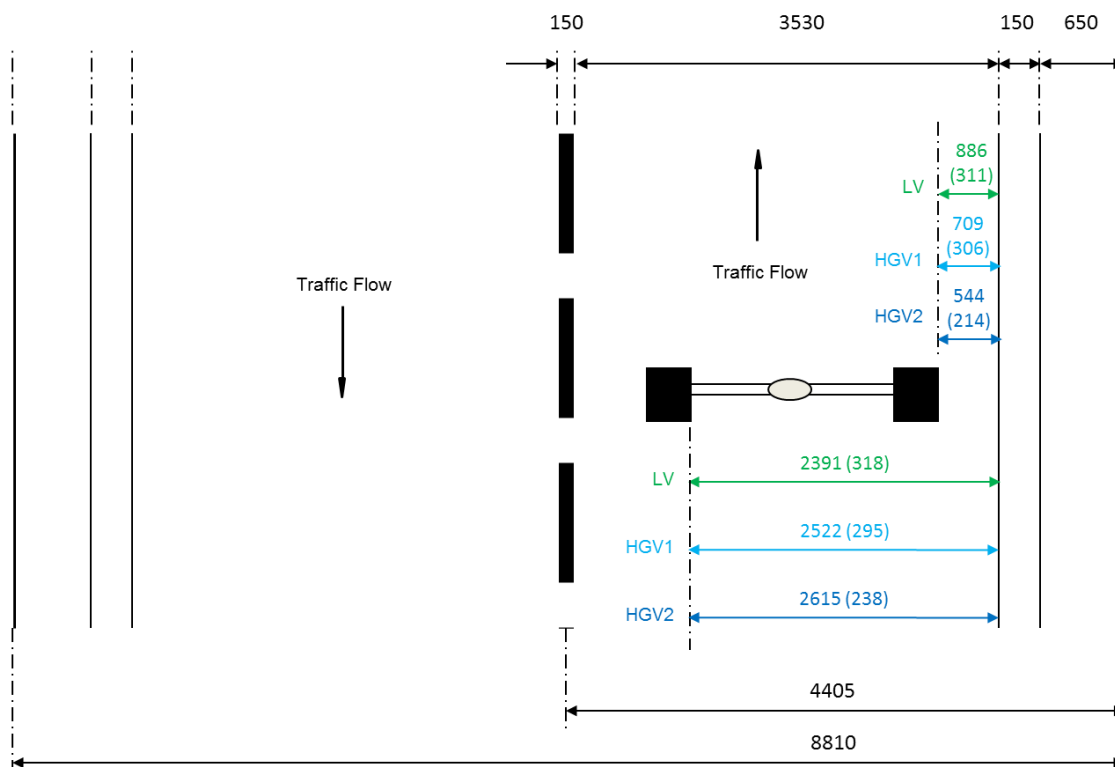


Figure 65. Ref 11 - Average Lateral Position and Standard Deviation.

Tyre tracking, assuming the following front tyre contact (with road surface) widths:

- light vehicles – 205 size = 175 mm surface contact width,
- HGV Group 1 – 295 size = 265 mm surface contact width, and
- HGV Group 2 – 385 size = 355 mm contact surface width.

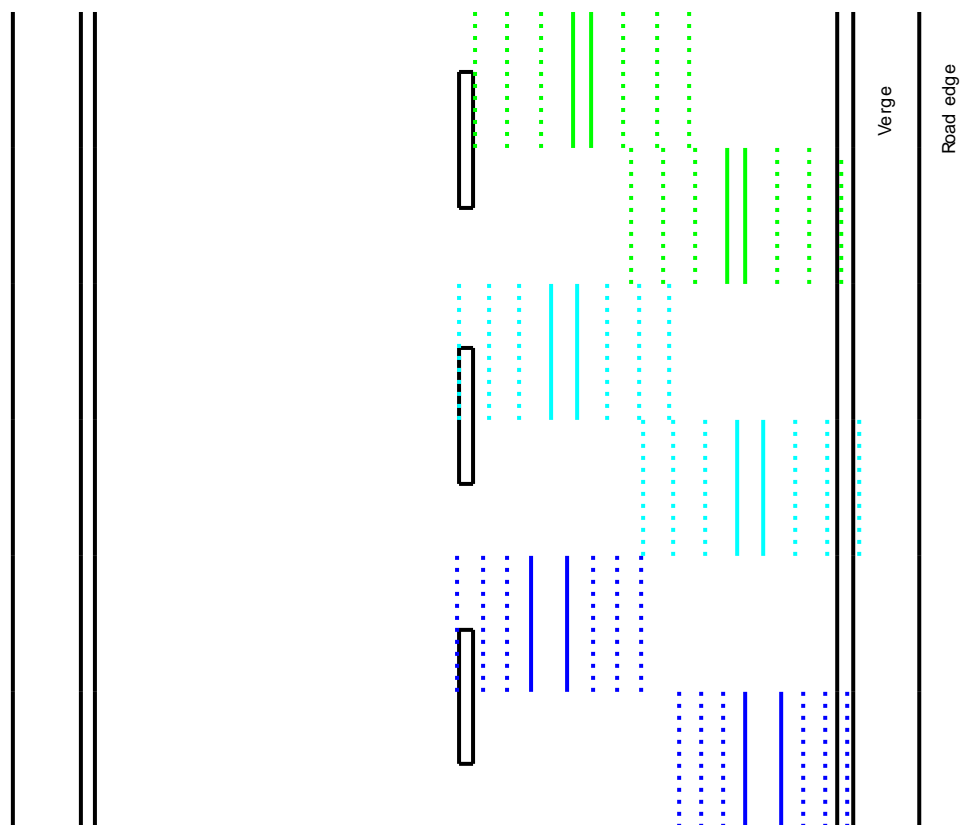


Figure 66. Ref 11 - Tyre Tracking.



Photograph 19. Ref 11. (Photo. Håkan Wilhelmsson).

Ref 12: Road 34, Linköping, National Route, Standard (8.6 m)

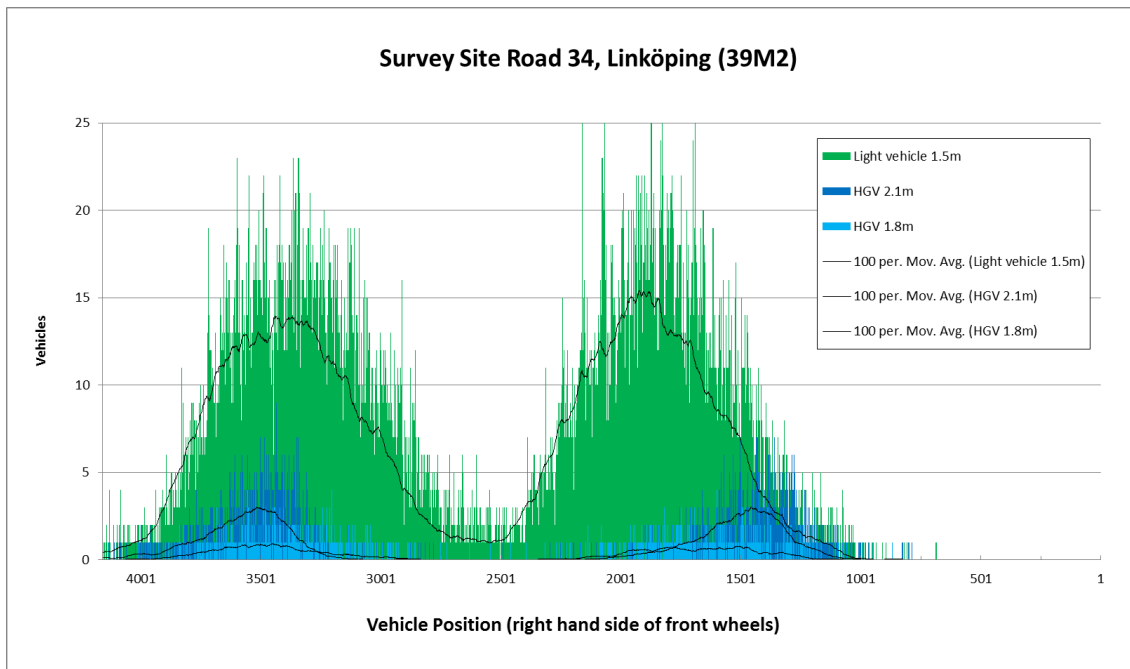


Figure 67. Ref 12 – Distribution of Lateral Position.

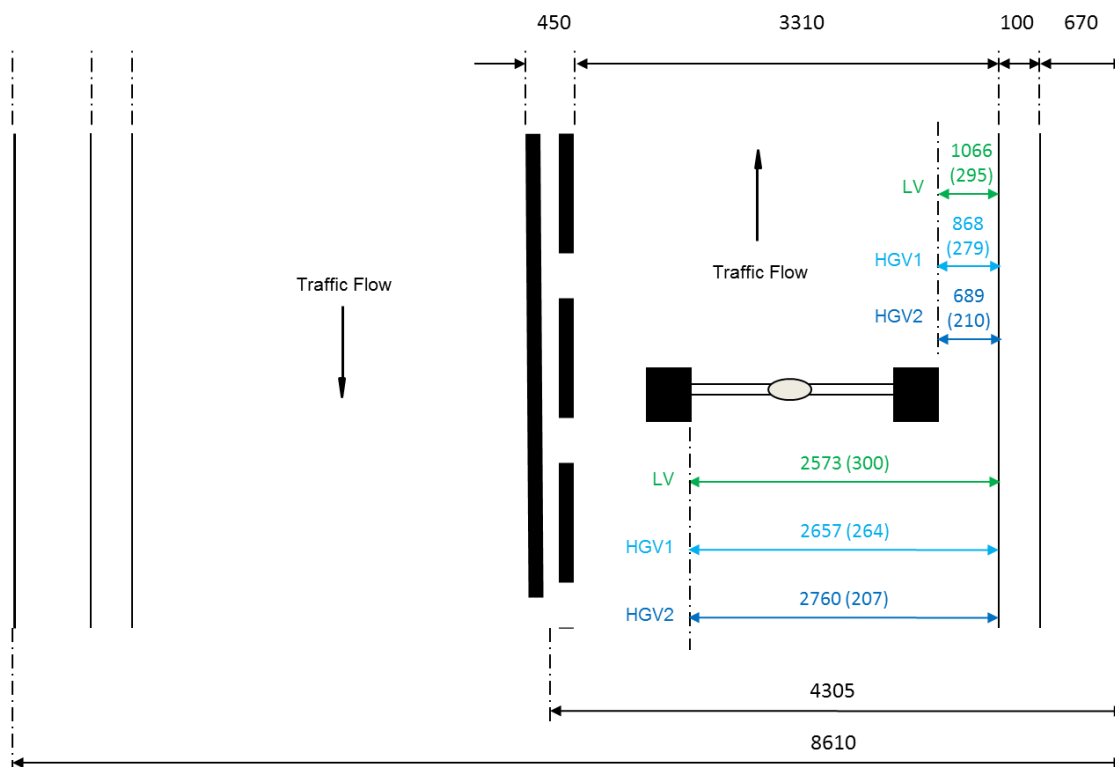


Figure 68. Ref 12 - Average Lateral Position and Standard Deviation.

Tyre tracking, assuming the following front tyre contact (with road surface) widths:

- light vehicles – 205 size = 175 mm surface contact width,
- HGV Group 1 – 295 size = 265 mm surface contact width, and
- HGV Group 2 – 385 size = 355 mm contact surface width.

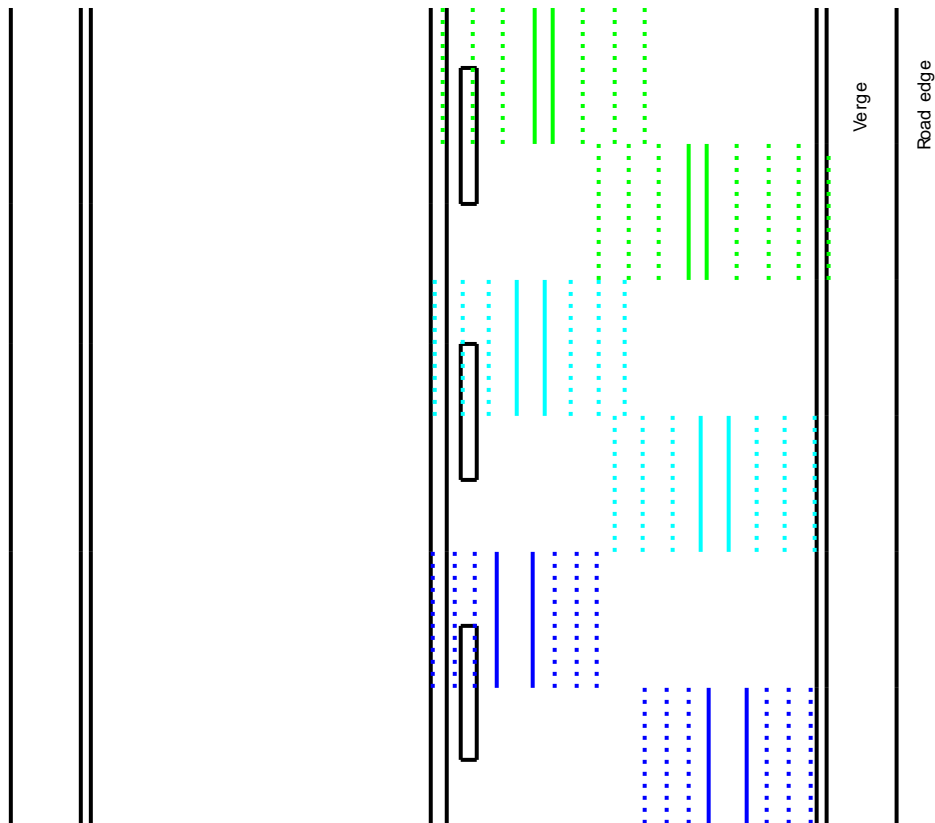


Figure 69. Ref 12 - Tyre Tracking.



Photograph 20. Ref 12. (Photo. Håkan Wilhelmsson).

Ref 13: Road 19, Skåne - Tranås, National Route, Standard (8.0 m)

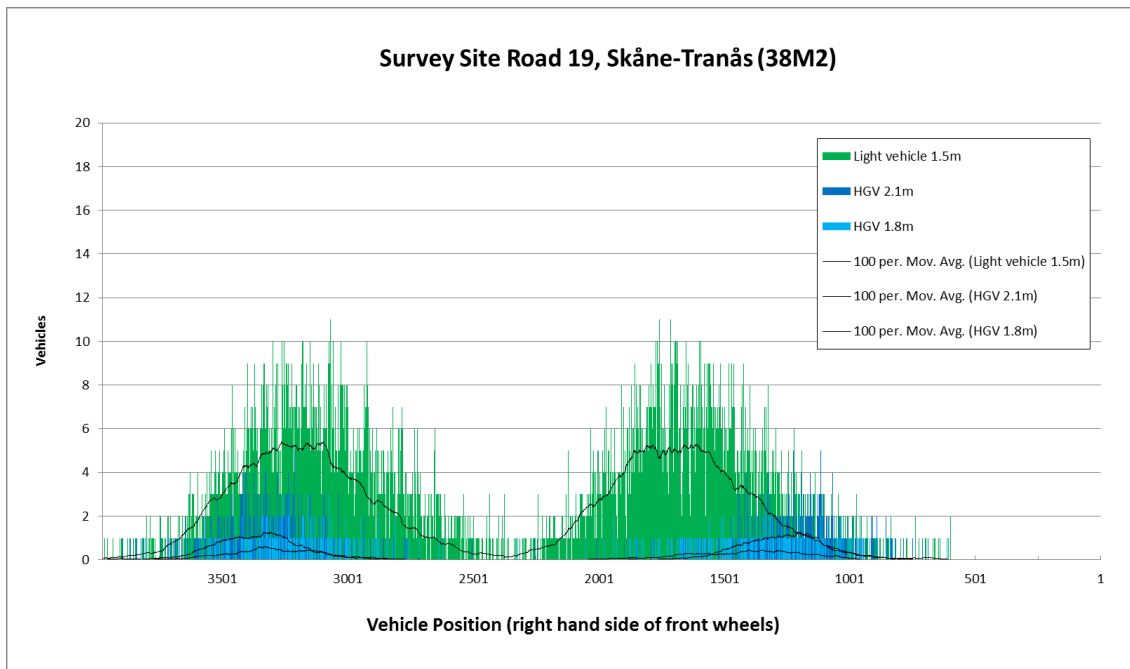


Figure 70. Ref 13 – Distribution of Lateral Position.

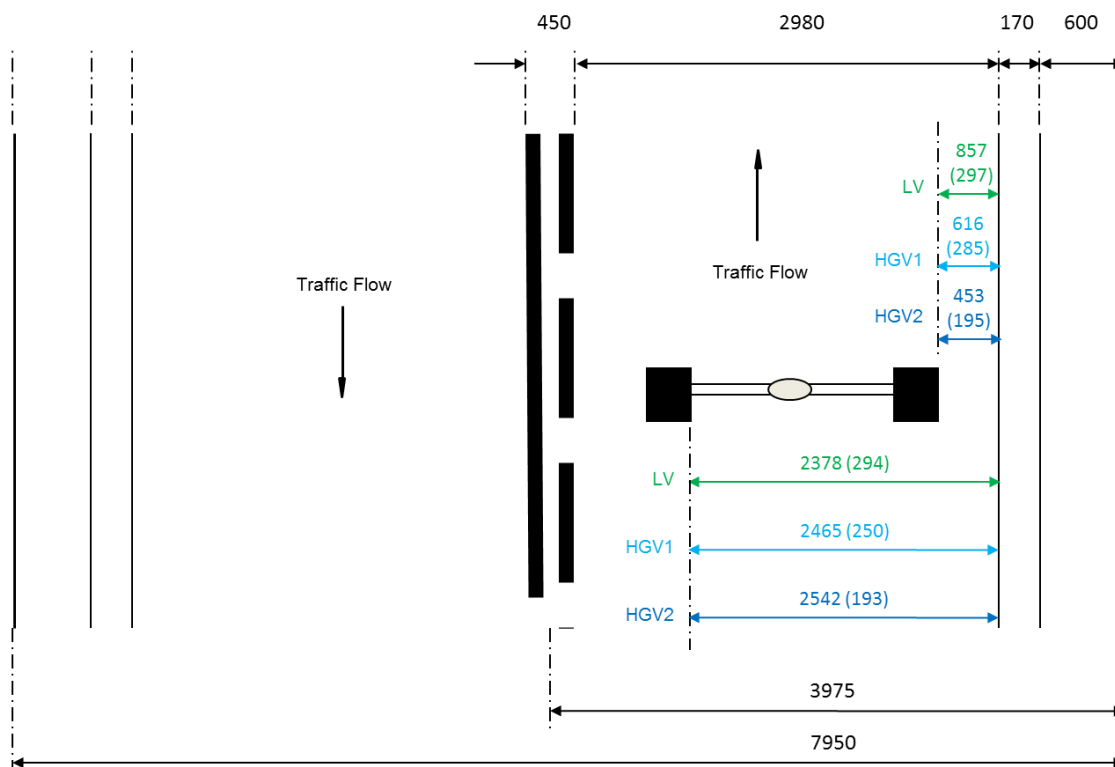


Figure 71. Ref 13 - Average Lateral Position and Standard Deviation.

Tyre tracking, assuming the following front tyre contact (with road surface) widths:

- light vehicles – 205 size = 175 mm surface contact width,
- HGV Group 1 – 295 size = 265 mm surface contact width, and
- HGV Group 2 – 385 size = 355 mm contact surface width.

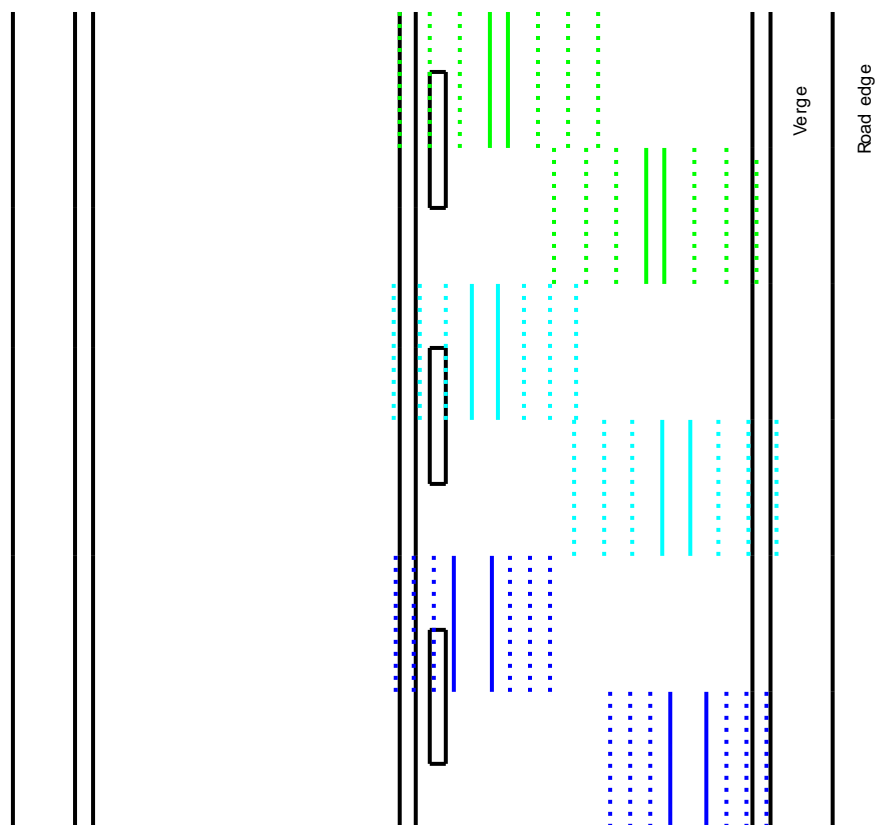


Figure 72. Ref 13 - Tyre Tracking.



Photograph 21. Ref 13. (Photo. Håkan Wilhelmsson).

Ref 14: Road 19, North of Brösarp, National Route, Standard (7.9 m)

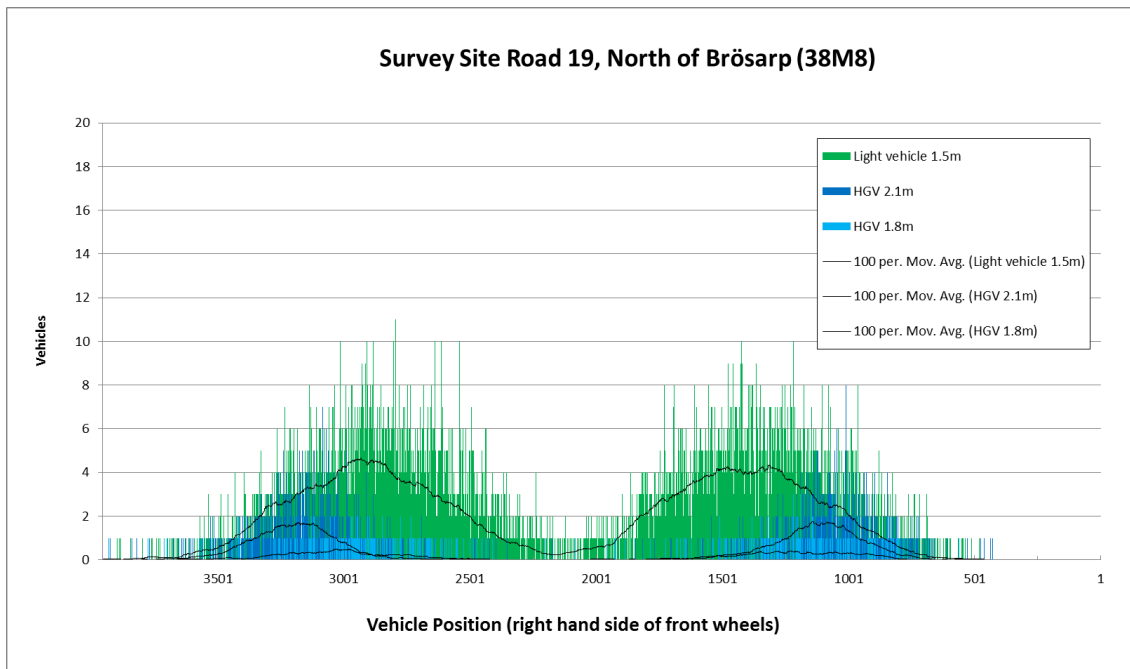


Figure 73. Ref 14 – Distribution of Lateral Position.

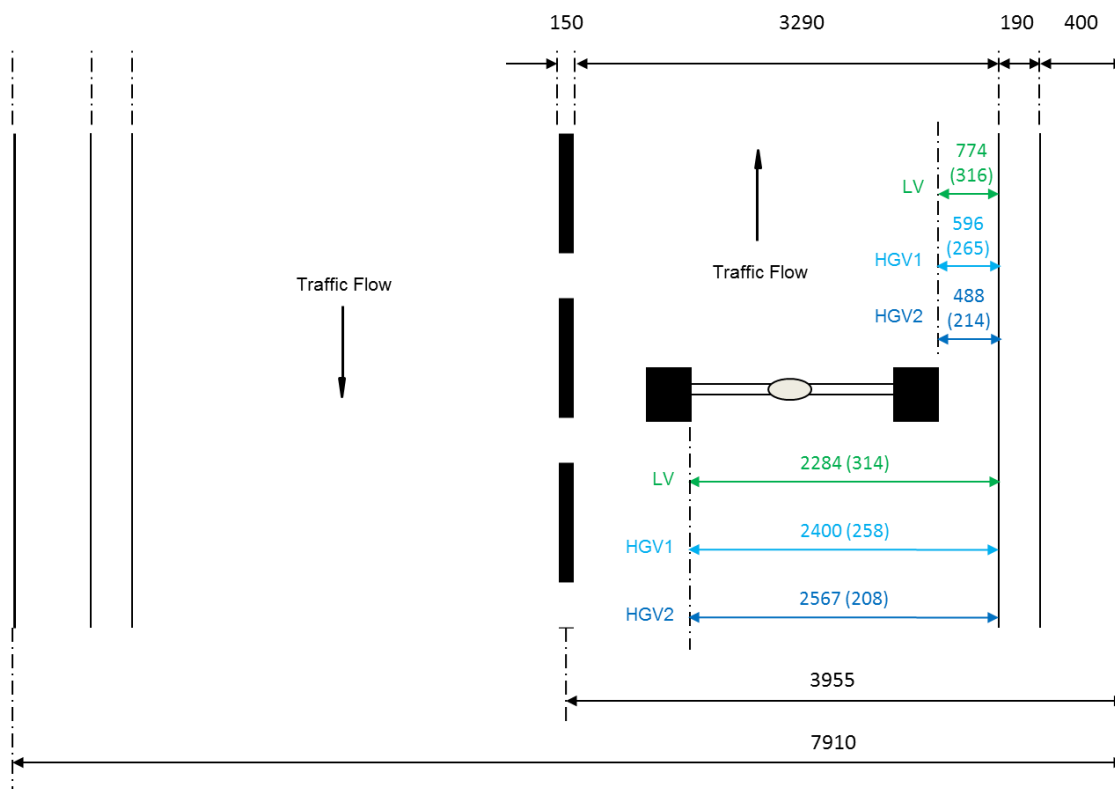


Figure 74. Ref 14 - Average Lateral Position and Standard Deviation.

Tyre tracking, assuming the following front tyre contact (with road surface) widths:

- light vehicles – 205 size = 175 mm surface contact width,
- HGV Group 1 – 295 size = 265 mm surface contact width, and
- HGV Group 2 – 385 size = 355 mm contact surface width.

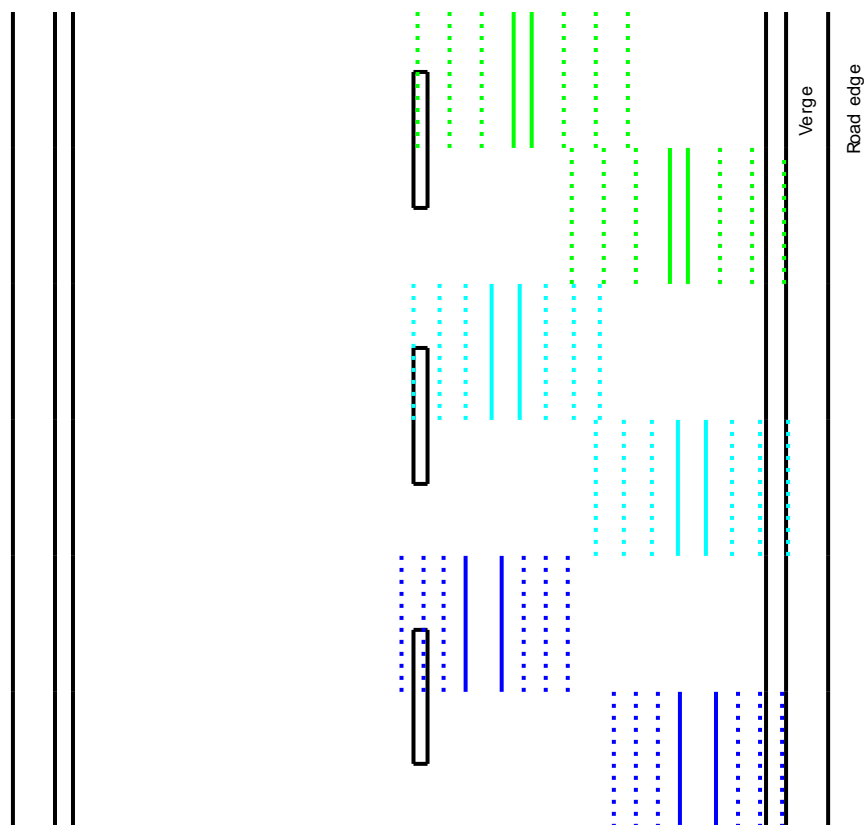


Figure 75. Ref 14 - Tyre Tracking.



Photograph 22. Ref 14. (Photo. Håkan Wilhelmsson).

Ref 15: Road 135, Gamleby, Primary Rural Road, Standard (7.7 m)

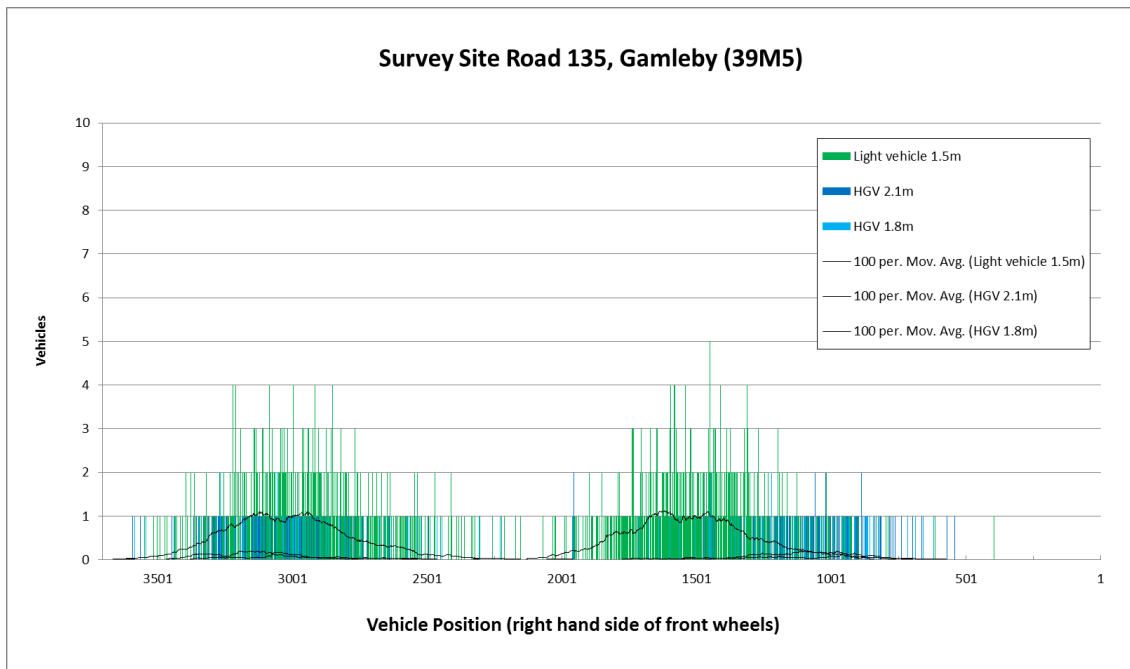


Figure 76. Ref 15 – Distribution of Lateral Position.

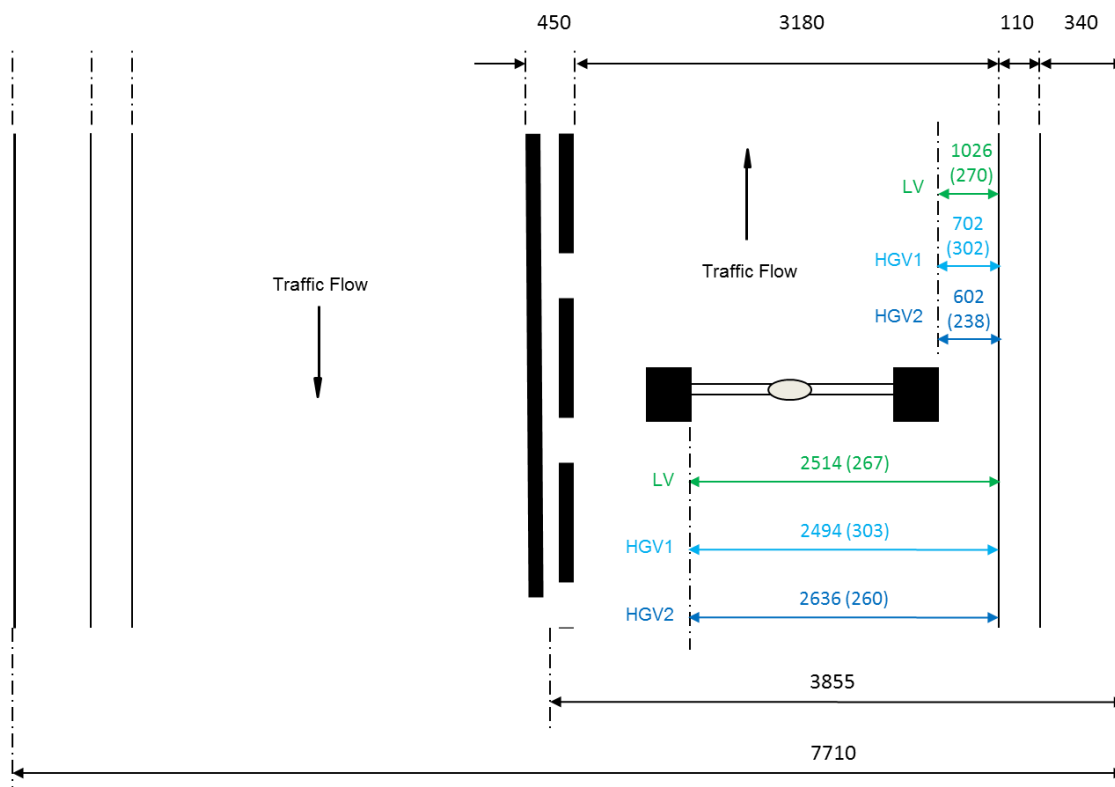


Figure 77. Ref 15. - Average Lateral Position and Standard Deviation.

Tyre tracking, assuming the following front tyre contact (with road surface) widths:

- light vehicles – 205 size = 175 mm surface contact width,
- HGV Group 1 – 295 size = 265 mm surface contact width, and
- HGV Group 2 – 385 size = 355 mm contact surface width.

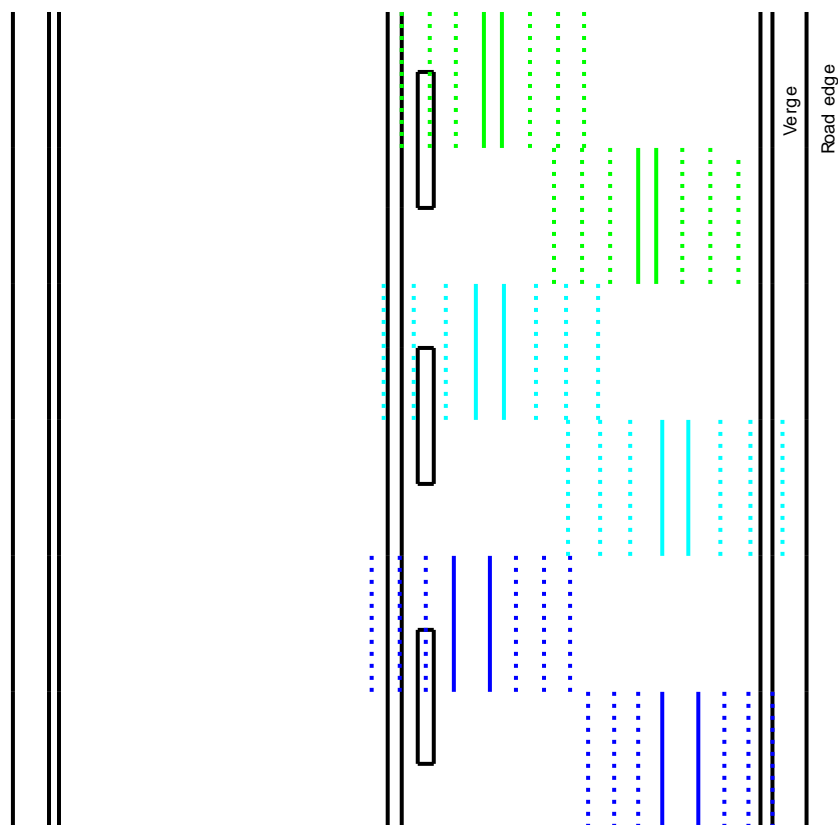


Figure 78. Ref 15 - Tyre Tracking.



Photograph 23. Ref 15. (Photo. Håkan Wilhelmsson).

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The Swedish National Road and Transport Research Institute (VTI), is an independent and internationally prominent research institute in the transport sector. Its principal task is to conduct research and development related to infrastructure, traffic and transport. The institute holds the quality management systems certificate ISO 9001 and the environmental management systems certificate ISO 14001. Some of its test methods are also certified by Swedac. VTI has about 200 employees and is located in Linköping (head office), Stockholm, Gothenburg, Borlänge and Lund.

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