MPD and IRI in the position of large goods vehicles

Network measurements

Olle Eriksson
Thomas Lundberg
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Abstract

Monitoring of the state road network in Sweden includes the longitudinal measurements of International Roughness Index (IRI) and Mean Profile Depth (MPD). This data can be used to predict values associated with rolling resistance, comfort and vehicle wear. The paths of the measurements correspond to the surface contact points of the wheels of a light passenger vehicle. In Sweden, lateral position comparisons made between medium and large goods vehicles show that right wheel track positions are not similar. This applies to larger and wider roads (typical motorways and other wide main roads). Knowledge of the surface conditions (IRI and MPD) at the surface contact points associated with a large goods vehicle would prove to be useful when predicting e.g. rolling resistance for large goods vehicles on entire or local road networks. If these conditions are not measured, it is important to know how they differ from the values in the measured path. Using this knowledge VTI’s measurement vehicle was equipped with two extra texture lasers which were mounted to the right of the ordinary texture laser in the right wheel track. Data was collected on a road network with mixed categories of road standard, from secondary roads to motorways.

During the study, differences in IRI and MPD values were analysed. Values corresponded to the position of light passenger vehicles right wheel paths and two other paths 25 centimetre and 45 centimetre further out to the right (position of medium and large goods vehicles). The possibility of predicting local differences (shorter sections) and average differences was analysed.

A statistical analysis procedure for calculating the mean difference and an error margin is suggested. Results showed that although it is very difficult to explain or predict local differences, average differences can be estimated.
Referat

Mätning av längsgående ojämnheter och makrotextur på det statliga vägnätet i Sverige inkluderar International Roughness Index (IRI) och Mean Profile Depth (MPD). Dessa data kan bland annat användas för att prediktera, rullmotstånd, komfort och fordonsslitage. De spår där mätningen av IRI och MPD sker motsvarar sidoläget för kontaktytan för däcken på en personbil.


I rapporten föreslås en statistisk analysmetod för att beräkna genomsnittlig skillnad och en felmarginal vid jämförelse mellan två olika sidolägen. Resultaten visade att det är svårt att förklara eller förutsäga lokala skillnader medan genomsnittliga skillnader och felmarginaler kan uppskattas.

Titel: MPD och IRI i sidoläget för tung trafik – Nätverksövergripande mätning
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Foreword

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Olle Eriksson and Thomas Lundberg
Quality review

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Kvalitetsgranskning

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Summary

MPD and IRI in the position of large goods vehicles – Network measurements

by Olle Eriksson (VTI) and Thomas Lundberg (VTI)

Road monitoring of the state road network in Sweden includes the longitudinal measurements of International Roughness Index (IRI) and Mean Profile Depth (MPD). The paths of the longitudinal measurements correspond with the surface contact points of the wheels of a light passenger vehicle. This data can be used to estimate values for different properties such as, rolling resistance, comfort and vehicle wear. Knowledge of the surface condition (IRI and MPD values) at the surface contact points associated with a large goods vehicle would prove to be useful when estimating similar values on an entire or local road network, including all vehicle types. If these conditions are not known, it is important to know how they differ from the measured path.

In Sweden, lateral position comparisons made between medium and large goods vehicles show that right wheel track positions are not similar. This applies to larger and wider roads (typical motorways and other wide main roads). Using this knowledge, VTI’s measurement vehicle was equipped with two extra texture lasers which were mounted to the right of the ordinary texture laser in the right wheel track. Data was collected on a road network with mixed categories of road standard varying from secondary roads to motorways.

The study of differences in IRI and MPD values, corresponding to the position of light passenger vehicles right wheel path and two other paths, 25 centimetre and 45 centimetre further out to the right (position of medium and large goods vehicles), showed rather small values in average differences. The differences are presented for different pavement types. An attempt to predict differences between the tracks for each 20-meter section failed. Inconsistent results meant that it was not possible to explain the differences. A statistical analysis procedure was used to calculate the global differences for the mean difference and error margin. The statistical analysis procedure is also presented in the report. The result for MPD showed very small global differences in the different lateral positions and normally the error margin is bigger than the average difference. Results regarding IRI values were more consistent. IRI values were greater closer to the road shoulder and the error margins were usually smaller than the differences. The difference in IRI and MPD between large goods vehicle (45 cm) and light passenger vehicle in the right wheel path for the two most common pavement categories, stone mastic asphalt (SMA) and dense asphalt concrete (DAC) were:

- SMA – 0.059 mm and error margin 0.024 mm for MPD
- DAC – 0.009 mm and error margin 0.048 mm for MPD
- SMA – 0.196 mm/m and error margin 0.026 mm/m for IRI
- DAC – 0.238 mm/m and error margin 0.075 mm/m for IRI
Sammanfattning

MPD och IRI i sidoläget för tung trafik – Nätverksövergripande mätning
av Olle Eriksson (VTI) och Thomas Lundberg (VTI)

Mätning av tillståndet på det statliga vägnätet i Sverige omfattar längsgående ojämnhet och makrotextur i form av International Roughness Index (IRI) och Medelprofildjup (MPD). Mätten mäts i det sidoläge som överensstämmer med kontaktytan för däcken på en personbil. Dessa data kan användas för att uppskatta värden för olika egenskaper som rullmotstånd, komfort och fordonslitage. Kunskap om yttillståndet (IRI och MPD) för kontaktytan hos en lastbil behövs vid bedömningen av liknande egenskaper för lastbilar både på vägnätsnivå och på objektnivå. Om tillståndet inte mäts för lastbilar, är det viktigt att veta hur de skiljer sig från de uppmätta.


Studien av skillnader för IRI och MPD i ordinarie position (personbilsposition) och mätningarna vid de två andra sidolägen som testades, 25 och 45 centimeter längre ut till höger (position för lastbilar), visade ganska små genomsnittliga värden. Skillnaderna presenteras för olika beläggningstyper. Ansatsen att förutse skillnaderna mellan spåren för varje 20 meterssträcka visade sig inte vara möjlig. Inkonsekventa resultat innebar att det inte var möjligt att förklara de lokala skillnaderna. En statistisk ansats användes för att beräkna genomsnittliga skillnader med tillhörande felmarginal. Ansatsen presenteras också i rapporten. Resultatet för MPD visade mycket små globala skillnader i olika sidolägen och normalt är felmarginalen större än den genomsnittliga skillnaden. Resultat avseende IRI-värdena var mer konsekvent. IRI var större närmare vägrenen och felmarginaler var oftast mindre än skillnaderna. Skillnaden i IRI och MPD mellan lastbilar och personbilar högra hjulspår (45 cm) för de två största beläggningskategorierna, asfaltbetong stenrik (ABS) och asfaltbetong tät (ABT) var:

- ABS – 0,059 mm och felmarginal 0,024 mm för MPD
- ABT – 0,009 mm och felmarginal 0,048 mm för MPD
- ABS – 0,196 mm/m och felmarginal 0,026 mm/m för IRI
- ABT – 0,238 mm/m och felmarginal 0,075 mm/m för IRI
1. **Background**

Road monitoring has a long history in Sweden. As early as 1987, International Roughness Index (IRI) (Sjögren L., 2014) was measured on all state roads. Macrotexture, expressed as Mean Profile Depth (MPD) (Lundberg T. et al., 2011) has a much shorter history. Measurements of MPD in Sweden started in 2005. Measurements are non-contact laser based and are carried out at normal traffic speed. The indicators are measured at different lateral positions in the road in order to monitor the condition where it is needed the most. The lasers measuring IRI and MPD have always had fixed lateral positions. The left and right hand side lateral position of the lasers corresponds with the distance between the wheels of a light passenger vehicle (private car, ~1.5 m).

An earlier pilot study of selected test sites (Lundberg T. et al., 2012) showed that there were large local differences of MPD and IRI values at different lateral positions in the road. Taking this knowledge into account, it was decided to study these differences on a road network basis.

Data from road surface monitoring can be directly used to make conclusions of the road condition. It can also be used in models which calculate or predict more complexed indexes and “higher” levels of decision based indexes such as environment impact, rolling resistance (Sandberg U., 2011), structural condition, comfort and vehicle wear.

Over time, more knowledge has become available and this has led to an increased demand and level of detail. As the possibility exists to increase the level of detail, indicators in turn will become refined. The model used for calculating the environmental impact of road/vehicle associated emissions uses IRI and MPD as input. The IRI and MPD variables used in the models for medium and large goods vehicles have so far not been discriminated. Even if differences are rather small, they can have a large impact on results when calculating the effect on a whole road network.
2. Purpose of this Study

The purpose of this study was to determine if there is a difference in IRI and MPD values for the right wheel path of different vehicle categories. This should be determined in order to increase knowledge of actual surface conditions at the road-vehicle interaction position for both medium and large goods vehicles.

The purpose was also to see if it was possible to estimate MPD and IRI values for large goods vehicles using IRI and MPD values associated with light passenger vehicles and explanatory variables like road width and pavement age.

During the study, two different approaches were tried:

- Local estimation – estimate the condition for each 20 m or 100 m section.
- Global estimation – estimate the condition for an entire group of roads of a given pavement category.

Local estimation could be used for object level calculations. Global estimation could be used when only mean values for an entire network is required.
3. Preparations and Measurements

3.1. Preparations of the Measurement Vehicle

Since the purpose of the study was to analyse differences in IRI and MPD values between the lateral positions of medium and large goods vehicles, we must first know the average lateral position of these vehicle types. This information was available from a recently finished but not yet published VTI project (McGarvey T., 2015). During this project, vehicle position surveys were carried out on different road categories ranging from 8m wide roads to motorways. Based on the projects results, the following assumptions can be made:

- On wide roads, medium and large goods vehicle tended to have the same left wheel lateral position
- In more confined or narrow roadways, all vehicle types tended to be positioned more centrally in the lane

The figure below is from the report described above (McGarvey T., 2015) and shows measurements of lateral position, in average and the standard deviation, for three different vehicle categories, light passenger vehicles (LV), medium goods vehicles (HGV 1) and large goods vehicles (HGV 2), on a motorway.

![Figure 1. Average lateral distance for different vehicle types. LV – light passenger vehicles, HGV 1 – medium goods vehicle and HGV2 – large goods vehicle. The standard deviation is presented within brackets. All distances in mm. (McGarvey T., 2015).](image)
Table 1. Summary of data from measurements of lateral position on motorway.

<table>
<thead>
<tr>
<th></th>
<th>Distance from Right Road Marking to Right Wheel (mm)</th>
<th>Standard Deviation (mm)</th>
<th>Distance from Right Road Marking to Left Wheel (mm)</th>
<th>Standard Deviation (mm)</th>
<th>Vehicle Track Width (m)</th>
<th>Estimated Front Tyre Width (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light passenger vehicle</td>
<td>995</td>
<td>456</td>
<td>2529</td>
<td>452</td>
<td>1.53</td>
<td>175</td>
</tr>
<tr>
<td>Medium goods vehicle</td>
<td>723</td>
<td>405</td>
<td>2528</td>
<td>372</td>
<td>1.81</td>
<td>265</td>
</tr>
<tr>
<td>Heavy goods vehicle</td>
<td>465</td>
<td>228</td>
<td>2557</td>
<td>224</td>
<td>2.10</td>
<td>355</td>
</tr>
</tbody>
</table>

Figure 2. Transverse profile measured at the photographs position and the lateral positions of the different vehicle types. (McGarvey T., 2015). (Picture: Swedish Road Administration)

The data from this measurement shows that the left wheels of all vehicle types are, on average, at the same position in the road. For the right hand side wheels, the distance between light passenger vehicle (LV) and medium goods vehicle (HGV1) is approximately 0.27 m and the distance between a light vehicle (LV) and heavy goods vehicle (HGV2) is, on average, 0.53 m. Due to restricted space on the frame holding the lasers, two extra lasers, used to measure macrotexture and unevenness, were mounted 0.25 m and 0.45 m from the laser that is normally used for macrotexture and unevenness. These positions correspond rather well with the optimal positions detailed in Figure 1.
3.2. Measurements

Measurements were carried out during the autumn of 2013. There was a wide distribution of major and minor road types, ranging from good quality secondary roads to motorways. The total length measured was just over 1000 km (Figure 3). Roads were measured in both directions. The vehicle driver was instructed to follow a driving line similar to the line driven by the network measurement vehicles.

Figure 3. Roads measured in the test.
4. Data Structure and Data Sources

A model that can explain how macrotexture and longitudinal unevenness differ between various wheel tracks locally also needs additional information about the road and the traffic. The explanatory variables used were annual average daily traffic (AADT), large goods vehicles annual average daily traffic (hAADT), road width, pavement stone size, and pavement age. The data structure and sampling procedure must be described in order to properly choose a model. Because different data sources were used, it was also important to describe if different sampling procedures were used in the different sources and how the data could be matched.

4.1. Road Network and Lowest Level Data Structure

An example of a road network is graphically illustrated in Figure 4 and can be described as follows:

- Roads are indicated with long lines.
- Each road is divided into sections. Black bullet points show where sections begin and end.
- Sections are divided into 20 m segments. Short lines, perpendicular to the section lines, indicate the beginning and end of each segment.
- Sections have different pavement types. Pavements are analysed one type at a time. All roads with a selected pavement type are marked with red. Roads with other pavement types are marked with black.
- Only a sample of sections are measured. The sample is marked with wider lines.
- There may be different pavement types within a section, as shown in one case where red and black colours appear on the same section. The entire section has been sampled but only the red part is used when analysing that selected pavement type.

![Figure 4. Schematic representation of sections and pavement types from the analysed network.](image-url)
Sections are divided into consecutive 20 m segments that fill the section without overlapping. The MPD values are probably correlated along a section, meaning that information in a 20 m segment is likely to be followed by approximately the same information in the next 20 m segment. This may be a problem when trying to define the number of independent observations. However, correlated values are not the same as correlated error terms and therefore do not create the same type of problems in the analysis.

4.2. Data Source

It was assumed that differences in MPD and IRI between wheel tracks could vary between pavement types. The dependence on other explanatory variables could also vary between pavement types. Because of this, it was crucial to identify the pavement type on the measured sections and that data and analyses could be split accordingly.

Information such as pavement type, AADT and road width was obtained from the Swedish Transport Administrations pavement management system (PMSv3). MPD and IRI was measured with VTIs road surface tester (RST). Data from the two sources was combined as follows:

- PMS and RST data were matched using section IDs. GPS coordinates were used to check overall shape and the start and finish points for each section. It was also possible to check that PMS and RST data was recorded in the same direction.
- PMS data was recorded mainly in 20 m segment lengths, however, some variation did occur. RST data was also available in 20 m segment lengths. In addition, PMS and RST data appeared to have had different drift in the distance data. Comparisons between the number of observations and measured lengths were performed on the PMS and RST data. If required, removal or stretching was also carried out to improve the matching.
- PMS data is updated each year but not for every road. Only PMS data from 2013, the same year as the RST data, was used.
- On occasion, the mean difference between tracks in the RST data appeared to be systematically too large to be relevant and correct. For that reason, some sections have been removed from the analyses.
- MPD and IRI is included in the PMS. However, data was only available for one of the tracks that was used in this report. MPD values for that track have been compared with the PMS and RST data as a control.
5. Analysis

Let MPD₀₀ be mean profile depth in the right wheel track. Also, let MPD₂₅ and MPD₄₅ be MPD in the tracks 25 cm and 45 cm to the right of the right hand side wheel track. The same indexes were used for IRI, though only MPD is used when discussing methods below. AADT, hAADT, road width, stone size and pavement age were also used. All explanation, analyses and results are meant to be read as representing one pavement type at the time.

5.1. Preliminary Analyses

In order to be able to suggest a model, it was necessary to determine the relationship between MPD₂₅ and MPD₀₀. Plotting the data and doing some preliminary analyses more or less showed that (MPD₂₅ − MPD₀₀) varied randomly around a constant level. Neither the level nor the variation increased with higher MPD₀₀.

A preliminary multiple linear regression model, \( MPD₀₀ = \beta₀ + \beta₁ \cdot MPD₂₅ + \beta₂ \cdot AADT + \cdots + \epsilon \), where the variation in MPD₂₅ can be explained by variations in MPD₀₀ and the other variable describing the road, looks promising with a high \( R^² \) etc. However, this is not recommended as a well-chosen analysis. Linear regression, with MPD₂₅ as response variable and MPD₀₀ as predictor variable, would use the data as if MPD₀₀ is "correct" while MPD₂₅ has random error. There is no reason to treat the MPD data in different tracks as if they have different levels of random error. Also, the high \( R^² \) arises from the fact that MPD₀₀ and MPD₂₅ are very similar but gives no information about how well the difference between MPD₂₅ and MPD₀₀ has been explained. A regression model with the difference in MPD between tracks as response variable, \( (MPD₂₅ − MPD₀₀) = \beta₀ + \beta₁ \cdot AADT + \cdots + \epsilon \), gave a poor result with \( R^² \) around 5%. It appears that there is a variation in the difference \( (MPD₂₅ − MPD₀₀) \), possibly with expected value different than 0, but it was not possible to suggest a model that described this difference using predictor variables.

Applying the same approach to the IRI data gave a similar poor result regarding a regression model. It was not possible to explain differences in IRI between wheel paths locally by using a regression model with other variables describing the road as explanatory variables.

5.2. Sampling Procedure

Sections were sampled and each segment within a sampled section was measured. There was no second stage sampling of segments. Samples were treated as a single stage cluster sample, where the sampling units are the sections while the elements are the segments. A section can be considered as a cluster of segments. Sampling a section is logically the equivalent to sampling a cluster of segments.

One observation in the data files referred to properties of a segment, however, segments were never sampling units. If sampling units and elements are not the same, the chosen analysis must be able to take care of this. This was not the case in the preliminary analyses, so it should be emphasised that they were preliminary.

Variation in data within a section was assumed to mainly reflect surface variation along the section and not random errors in the measurements. It is probable that surface properties vary, often by a small amount, along the section, causing the observations to be longitudinally correlated within a section. This serial correlation in the surface data does not give any problems in the analysis when all segments in a section are used.

The driver of the RST had an instruction about which lateral position to follow. Because the lateral position cannot be followed with absolute precision, it may be necessary to also discuss lateral position as a “sample”. On short distances, the lateral position compared to the ideal track probably has serial correlation. On longer sections, any effect of the lateral position should level out and will not be disturbed by serial correlation of the position. If the position varies within sections to such an
extent that it does not level out, then that will be part of the variation between sections, which is also included as an error in the final analysis.

5.3. Final Analysis

The total of all observations in cluster \( i \), \( y_i \), is the sum of deviations between \((MPD_{25} - MPD_{00})\) on that section. The size of cluster \( i \), \( m_i \), is the length expressed as the number of 20 m segments. If a section had different pavement types, then both \( y \) and \( m \) refer to the part of the section that had the selected pavement type. The population mean, \( \mu \), is the average difference of \((MPD_{25} - MPD_{00})\) over the entire road network. It is the population sum of all deviations over all segments divided by the number of segments. If the network had \( N \) sections, then \( \mu = \frac{\sum_{i=1}^{N} y_i}{\sum_{i=1}^{N} m_i} \). The corresponding estimator for a sample of \( n \) clusters is the sample sum of all deviations divided by its number, that is \( \hat{\mu} = \frac{\sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} m_i} \).

The sections had varying lengths. For road network measurement, longer sections should have larger weight. If \( \bar{y}_i \) is the average of \((MPD_{25} - MPD_{00})\) on section \( i \), then the mean can alternatively be written as \( \mu = \frac{\sum_{i=1}^{n} m_i \bar{y}_i}{\sum_{i=1}^{n} m_i} \). This is a weighted mean of the section means, with weights proportional to section length. The estimator also has that structure and is a ratio of random variables. The variance for ratios of this type does not normally have closed form expressions, but known approximations exist. In this case, if \( \bar{m}_i \) is the average section length in the sample, then the variance of \( \hat{\mu}, \hat{\sigma}_\mu \), is approximately \( \frac{1}{nm^2}, \frac{\sum_{i=1}^{n}(y_i - \hat{\mu}m_i)^2}{n-1} \). This can be adjusted if the number and average length of sections in the network are known. In this case it was assumed that this information was not available. The method should not be used for samples that only include a few clusters. An error margin for the mean difference and is \( 2\sqrt{\hat{\sigma}_\mu} \).

Data can also be summarised by using standard deviation (SD) within sections that describes how \((MPD_{25} - MPD_{00})\) vary between 20 m segments and SD between sections that describes how the sample mean difference varies between sections.

As can be seen above, only equations for the difference \((MPD_{25} - MPD_{00})\) were discussed. However, the same method can be used for \((MPD_{45} - MPD_{00})\) without further explanation as long as no assumption is made about how these two differences relate to each other. IRI was also analysed using the same method.
6. Results

6.1. Summarised Numerical Results

Table 2 summarises the measured differences ($\text{MPD}_{25} - \text{MPD}_{00}$) for different pavement types while Table 3 summarises the results for ($\text{MPD}_{45} - \text{MPD}_{00}$).

### Table 2. Results for the difference ($\text{MPD}_{25} - \text{MPD}_{00}$).

<table>
<thead>
<tr>
<th>Type of coating</th>
<th>SD Within Sections</th>
<th>SD Between Sections</th>
<th>Mean Difference</th>
<th>Error Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stone Mastic Asphalt</td>
<td>SMA</td>
<td>0.080</td>
<td>0.047</td>
<td>0.011</td>
</tr>
<tr>
<td>Dense Asphalt Concrete</td>
<td>DAC</td>
<td>0.089</td>
<td>0.040</td>
<td>-0.012</td>
</tr>
<tr>
<td>Stone Mastic Asphalt, Hard Binder</td>
<td>HABS</td>
<td>0.070</td>
<td>0.027</td>
<td>0.021</td>
</tr>
<tr>
<td>Asphalt Concrete, Binder Course</td>
<td>ABb</td>
<td>0.093</td>
<td>0.018</td>
<td>-0.020</td>
</tr>
<tr>
<td>Dense Asphalt Concrete, Soft Binder</td>
<td>MABT</td>
<td>0.101</td>
<td>0.042</td>
<td>0.002</td>
</tr>
<tr>
<td>Thin Surface Course System</td>
<td>TSCS</td>
<td>0.116</td>
<td>0.045</td>
<td>-0.019</td>
</tr>
<tr>
<td>Dense Asphalt Concrete, Hard Binder</td>
<td>HABT</td>
<td>0.090</td>
<td>0.093</td>
<td>0.033</td>
</tr>
</tbody>
</table>

Overall, there was more variation within sections than between sections. Mean differences were small and with different sign and often less than the error margins. The variation in ($\text{MPD}_{25} - \text{MPD}_{00}$) was smaller than the variation in ($\text{MPD}_{45} - \text{MPD}_{00}$). The mean difference had no clear comparable pattern between ($\text{MPD}_{25} - \text{MPD}_{00}$) and ($\text{MPD}_{45} - \text{MPD}_{00}$), however, error margins were generally smaller in ($\text{MPD}_{25} - \text{MPD}_{00}$).

The results indicate that MPD values, 25 cm and 45 cm to the right of the right wheel track, had about the same MPD values found in the right wheel track position. There was some variation in the differences compared to the right wheel track. These differences varied more within sections than between sections. They cannot easily be explained by the use of predictor variables such as AADT and road width.

IRI values at different lateral positions were analysed in the same way as the MPD data. Results showed that it was not possible to determine a model that could explain the differences locally. However, the level of global standard deviation within and between sections, as well as average...
differences and error margins, can be presented. The global average results for IRI data were more consistent than with the results for MPD data. IRI values were larger for positions further out to the right of the lane. In addition, error margins were in most cases smaller than the differences. Comparisons of the same pavement category showed that $(\text{IRI}_{45} - \text{IRI}_{00})$ were always greater than $(\text{IRI}_{25} - \text{IRI}_{00})$. All of the results can be seen in Table 4 and 5.

**Table 4. Results for the difference (IRI$_{25}$-IRI$_{00}$)**

<table>
<thead>
<tr>
<th>Material</th>
<th>SD Within sections</th>
<th>SD Between sections</th>
<th>Mean Difference</th>
<th>Error Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stone Mastic Asphalt</td>
<td>SMA</td>
<td>0.259</td>
<td>0.053</td>
<td>0.044</td>
</tr>
<tr>
<td>Dense Asphalt Concrete</td>
<td>DAC</td>
<td>0.248</td>
<td>0.104</td>
<td>0.074</td>
</tr>
<tr>
<td>Stone Mastic Asphalt, Hard Binder</td>
<td>HABS</td>
<td>0.327</td>
<td>0.074</td>
<td>0.114</td>
</tr>
<tr>
<td>Asphalt Concrete, Binder Course</td>
<td>ABb</td>
<td>0.318</td>
<td>0.131</td>
<td>0.206</td>
</tr>
<tr>
<td>Dense Asphalt Concrete, Soft Binder</td>
<td>MABT</td>
<td>0.635</td>
<td>0.178</td>
<td>0.419</td>
</tr>
<tr>
<td>Thin Surface Course System</td>
<td>TSCS</td>
<td>0.143</td>
<td>0.032</td>
<td>0.010</td>
</tr>
<tr>
<td>Dense Asphalt Concrete, Hard Binder</td>
<td>HABT</td>
<td>0.146</td>
<td>0.020</td>
<td>0.071</td>
</tr>
</tbody>
</table>

**Table 5. Results for the difference (IRI$_{45}$-IRI$_{00}$)**

<table>
<thead>
<tr>
<th>Material</th>
<th>SD Within sections</th>
<th>SD Between sections</th>
<th>Mean Difference</th>
<th>Error Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stone Mastic Asphalt</td>
<td>SMA</td>
<td>0.675</td>
<td>0.108</td>
<td>0.196</td>
</tr>
<tr>
<td>Dense Asphalt Concrete</td>
<td>DAC</td>
<td>0.356</td>
<td>0.145</td>
<td>0.238</td>
</tr>
<tr>
<td>Hard Binder, Stone Mastic Asphalt</td>
<td>HABS</td>
<td>0.492</td>
<td>0.059</td>
<td>0.238</td>
</tr>
<tr>
<td>Asphalt Concrete, Binder Course</td>
<td>ABb</td>
<td>0.402</td>
<td>0.196</td>
<td>0.355</td>
</tr>
<tr>
<td>Soft Binder, Dense Asphalt Concrete</td>
<td>MABT</td>
<td>0.849</td>
<td>0.169</td>
<td>0.696</td>
</tr>
<tr>
<td>Thin Surface Course System</td>
<td>TSCS</td>
<td>0.197</td>
<td>0.053</td>
<td>0.133</td>
</tr>
<tr>
<td>Hard Binder, Dense Asphalt Concrete</td>
<td>HABT</td>
<td>0.232</td>
<td>0.020</td>
<td>0.212</td>
</tr>
</tbody>
</table>

6.2. Recommendations for Use

The results in this study should be used according the following summary,

- **Regarding MPD** – the results indicate that MPD differences between different lateral positions is small. The measured MPD for light passenger vehicles can be used to approximate MPD for medium and large goods vehicles.

- **Regarding IRI** – the results indicate that IRI in different lateral positions cannot be neglected. When using IRI-condition for medium and large goods vehicles and only IRI-levels are available for the positions of light passenger vehicles the results according the tables 4 and 5 should be added to the measured IRI values.

This applies for network calculations, not at object level. Which of the tables 4 and 5 to use when estimating IRI for medium and large goods vehicle depends on the type of road (road width) and for what type of vehicle you should estimate the IRI-condition. Results from studies of lateral position at different...
road width and with different vehicles types (McGarvey T., in progress) should be used to determine which of the tables to use. A brief suggestion is to use IRI-differences according Table 4 when estimating IRI for large goods vehicles at narrow roads and IRI differences for large goods vehicles according Table 5 for wider roads.
7. Discussion

It was not possible to suggest a model that could explain $MPD_{25}$ or $MPD_{45}$ for 20 m or 100 m segment lengths by using $MPD_{00}$ and prediction variables such as AADT and road width. Suggestions, on how to predict $MPD_{25}$ or $MPD_{45}$ or its difference against $MPD_{00}$, could not be made for 20 m segments or entire sections. However, it was possible to estimate the mean differences ($MPD_{25} - MPD_{00}$) and ($MPD_{45} - MPD_{00}$) aggregated to road network level. Error margin suggestions for that estimate can also be made. Restrictions on how ($MPD_{25} - MPD_{00}$) and ($MPD_{45} - MPD_{00}$) should relate to each other have not been included. IRI data was analysed in the same way as the MPD data and led to the same conclusions regarding use of explanatory variables, model selection etc.

The differences ($MPD_{25} - MPD_{00}$) and ($MPD_{45} - MPD_{00}$) were analysed separately. A possible improvement of the analysis could be to compare all three wheel tracks at the same time. If it is assumed that ($MPD_{45} - MPD_{00}$) has the same sign and is greater than ($MPD_{25} - MPD_{00}$), the assumption can be tested and, if it appears to be correct, be restricted according to that.

For better precision in the estimates, a new sample should include many sections. With this type of data structure, using data collected from a few long sections does not improve the estimate precision by much. It is the difference between sections that is most important, meaning that many sections should be used to improve the estimation.

If the data is regarded as a two stage cluster sample, it is also possible to include the variation within clusters in the error margin. It is, however, unclear how that should be done. There is no sampling of 20m section in a second stage. The idea would rather be to estimate the random error within sections (due to measurement noise, driver behavior etc.) and include them in the error margin as if the finite sample correction was not zero in the second stage.

The estimation method used was derived for a truly random sample of sections, but the sampling in this study was not carried out exactly in that way. This does not necessary result in a drawback because some sampling techniques, other than simple random sampling, may improve the precision of the results. However, some difficulties are possible when trying to express how much the precision was improved. Sections have to some degree been selected, but MPD was not one of the selection criteria. In this case, it is reasonably considered that the method was well chosen and that the results were reliable.

In this study, the sample included different road widths, different pavement ages etc. and should be regarded as having the same benefits as a systematic sample.
References


McGarvey T. (In progress), Variation of Vehicle Lateral Position – According to Road Type and Lane Width, VTI report


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.