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Mobile measurement of road marking performance

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Abstract

This study describes an attempt to improve the model which so far has been used for prediction of wet road marking retroreflectivity when using mobile equipment. A texture measure which better should reflect the wet weather performance of road markings, then the one which has been used up to now, was developed. From field measurements, the new prediction model was developed and evaluated.

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Referat

Denna studie beskriver ett försök att förbättra precisionen vid prediktion av våta vägmarkeringars retroreflexion, baserad på mobil mätning. Inom projektet har utvecklats ett texturmått som bättre bör beskriva den våta vägmarkeringens funktion, än det texturmått som hittills har använts. Därefter har en ny prediktionsmodell, baserad på fältmätningar, utvecklats.

Titel:	Utveckling av en prediktionsmodell för våta vägmarkeringars retroreflektion – mobil mätning av vägmarkeringars funktion.
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Preface

This study has been accomplished in the scope of the Nordic Research Collaboration, NordFoU, thus jointly funded by the Danish Road Directorate, the Finnish Transport Agency, the Norwegian Public Roads Administration and the Swedish Transport Administration.

From the above mentioned road authorities a steering committee was formed: Bjarne Schmidt (chairman), Denmark, Tuomas Österman, Finland, Björn Skaar, Norway and Lars Petersson, Sweden.

The study was coordinated by Bjarne Schmidt, the Danish Road Directorate, Kai Sørensen, Johnsen Consulting, Berne Nielsen, Ramböll RST and Sven-Olof Lundkvist, VTI. Bjarne Schmidt was the project leader, Kai Sørensen was responsible for the theoretical considerations and evaluation of a programme for determination of the texture factor, Berne Nielsen was responsible for the field measurements and Sven-Olof Lundkvist for the analysis and documentation.

Linköping, November 2015

Sven-Olof Lundkvist
Project leader

Quality review

Internal peer review was performed on 14 December 2015 by Sara Nygårdhs. Sven-Olof Lundkvist has made alterations to the final manuscript of the report. The research director Anne Bolling examined and approved the report for publication on 19 January 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 14 december 2015 av Sara Nygårdhs. Sven-Olof Lundkvist har genomfört justeringar av slutligt rapportmanus. Forskningschef Anne Bolling har därefter granskat och godkänt publikationen för publicering 19 januari 2016. De slutsatser och rekommendationer som uttrycks är författarens/författarnas egna och speglar inte nödvändigtvis myndigheten VTI:s uppfattning.

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Summary

Development of a prediction model for wet road marking retroreflectivity – mobile measurement of road marking performance.

by Sven-Olof Lundkvist (VTI), Kai Sørensen (Johnson Consulting) and Berne Nielsen (Ramböll RST)

During the last ten years, ***dry*** road marking retro reflectivity has been measured by the use of mobile equipment. However, due to a growing interest in the performance of ***wet*** road markings, the use of road markings with a profiled surface is common in many European countries today. When measuring this type of marking with the use of mobile equipment in wet weather conditions, one problem arises: The measured retroreflectivity will be affected by splash from the wheels of the measurement vehicle, which can be avoided only by driving extremely slowly. Therefore, in order to carry out measurement at the speed of surrounding traffic, measurements must be accomplished on dry road markings.

So far, regarding mobile measurement, wet road marking retroreflectivity has been predicted using a model involving the dry road marking retroreflectivity and the mean profile depth, *MPD*, of the profile. However, the precision of the predictions is poor and there is a desire to improve the model. One hypothesis is that another measure than *MPD* would have a higher predictive value. This measure should take into account the area of all facets that are oriented in directions towards the driver.

In a first step of the study the so-called texture factor, *T*, was developed. In short, this texture factor calculates the sum of the luminous flux from all road marking facets which are visible to the driver. In the next step, using results from field measurements, a prediction model was developed and evaluated.

The result shows that the fundamental hypothesis can be accepted: The texture factor is a better predictor of the retroreflectivity of a wet road marking than *MPD* is. The average difference between measured and predicted values was found being 5.0 mcd/m^2/lx, which is an improvement from 5.6 mcd/m^2/lx when using *MPD*. However, even if the improvement is significant, it was expected to be larger. The reason for this relatively small improvement is probably the contribution from micro beads on some road markings, but not on others. One hypothesis is that if the surface of the profile is almost vertical, the water will run off and the beads appear, thus contributing to the retroreflectivity. Therefore, the improvement of the model would probably be much larger if an indicator for contributing micro beads was also included. An attempt to do so was done, however without success, partly explained by too little data to split the analysis into two subsets; one with contributing beads and one without.

The conclusion of this study is that an important step towards a better prediction model for wet road marking retroreflectivity was taken. However, collection of more data and the introduction of an indicator for contribution from glass beads would probably improve the model even more.

Sammanfattning

Utveckling av en prediktionsmodell för våta vägmarkeringars retroreflektion – mobil mätning av vägmarkeringars funktion.

av Sven-Olof Lundkvist (VTI), Kai Sørensen (Johnson Consulting) och Berne Nielsen (Ramböll RST)

Under de senaste tio åren har ***torra*** vägmarkeringars retroreflektion kunnat mätas mobilt. Intresset för ***våta*** vägmarkeringars funktion har emellertid ökat och profilerade vägmarkeringar används i allt större utsträckning. Det är dock svårt att göra mobil mätning på våta vägmarkeringar eftersom stänk från mätfordonets däck riskerar att påverka resultatet. Därför måste mätning i vått väglag göras i mycket låg hastighet. Emellertid är en strävan att utföra mätningen i övrig trafiks hastighet, men då måste vägbanan vara torr.

Hittills har våta vägmarkeringars retroreflektion predicerats med en statistisk modell som använder den torra markeringens retroreflektion och dess medelprofildjup (*MPD*) som prediktorer. Tyvärr blir prediktionen behäftad med ganska stor osäkerhet, varför det finns ett behov av att förbättra dess noggrannhet och precision. En hypotes är att det bör finnas texturmått som bättre speglar markeringens våtfunktion än vad *MPD* gör. En sådan variabel bör beskriva den sammanlagda arean av profilens ytor som är orienterade i riktning mot föraren.

I ett första steg av studien utvecklades den så kallade texturfaktorn, *T*. Kortfattat kan denna variabel sägas beräkna summan av ljusflödet från de ytor som är synliga för en fordonsförare. Därefter utvecklades och validerades en statistisk prediktionsmodell, baserad på fältmätningar.

Resultaten visar att hypotesen kan accepteras: Texturfaktorn, *T*, beskriver bättre den våta vägmarkeringens retroreflektion än vad *MPD* gör. Medelavvikelsen mellan observerade och predicerade värden var 5,0 mcd/m^2/lx, vilket är en förbättring från 5,6 mcd/m^2/lx då *MPD* används som texturmått. Även om en förbättring av prediktionerna kunde redovisas, var förhoppningen att denna förbättring skulle vara större. Att så inte blev fallet kan sannolikt förklaras av att för vissa vägmarkeringar bidrar glaspärlorna till retroreflexion, även i vått väglag. Om profilen är nästan vertikal är det möjligt att vattnet rinner av glaspärlorna och att dessa då framträder och får en viss retroreflekterande funktion. Modellen skulle därför sannolikt predicera mer korrekta värden om den också hade en variabel som indikerar om glaspärlorna bidrar till retroreflexionen eller ej. Det gjordes ett försök att tillföra en sådan indikator, som emellertid inte lyckades, vilket skulle kunna förklaras av att datamängden var alltför liten för att splittras i två delar – markeringar med och markeringar utan bidragande glaspärlor.

Slutsatsen av föreliggande studie är att ett stort steg mot en modell som bättre predicerar våta vägmarkeringars retroreflektion har tagits. Emellertid skulle en ytterligare förbättring kunna uppnås genom att införa en indikator för huruvida glaspärlor bidrar eller ej. För detta krävs dock mer data.

1. Background and project organization

During the last ten years, ***dry*** road marking retroreflectivity has been measured by the use of mobile equipment. However, due to a growing interest in the performance of ***wet*** road markings, today, the use of road markings with a profiled surface is common in many European countries. The performance in wet conditions may be possible to measure using a wetting vehicle just ahead of the mobile equipment or maybe carry out measurement during rain. However, both methods are unpractical due to splash on the lenses of the reflectometer, which will affect the readings. Therefore, in order to carry out measurement at the speed of the other traffic, measurements must be accomplished on dry road markings.

The goal of the present study is to find an equation which describes the relationship between, on one hand, the wet road marking performance in night-time driving and, on the other hand, the performance in dry condition. The independent variables in this equation must be possible to measure at the speed of the surrounding traffic. This is important, not only for the safety of the operator, but also for traffic safety in general.

In a study 2008 (Lundkvist, Johansen, Nielsen, 2008), a correlation between, on one hand the retroreflectivity of the wet road marking, and on the other hand the retroreflectivity of the dry marking and its mean profile depth (*MPD*), was established. The relationship is positive, which means that high retroreflectivity in dry condition and a large macro-texture, implies good wet weather performance. However, the uncertainty in the predicted retroreflectivity of the wet road marking was poor; a 90% prediction interval was of the size ± 16 mcd/m^2/lx, which means that the uncertainty of the predicted value on average is ± 9 mcd/m^2/lx. For many applications this interval is too large, as the average value of the retroreflectivity mostly is in the range 10 to 50 mcd/m^2/lx. Consequently, there is an urgent need to develop a model which has less uncertainty. Hopefully, the introduction of a "texture factor", *T*, would improve the model.

The work on finding a new texture factor and a better prediction model has been organized as follows:

1. project management. (The Danish Road Directorate)
2. theoretical considerations. (Johnson Consulting)
3. development of a computer programme calculating the texture factor. (Johnson Consulting)
4. field measurements. (Ramböll and VTI)
5. statistical analysis. (VTI)
6. documentation. (VTI).

2. Aim of the study and theory

The aim of this study is to find a prediction model

$$R_L(wet) = A + B \cdot R_L(dry) + C \cdot T + D \cdot \beta \quad (1)$$

where

$R_L(wet)$ is the retroreflectivity of the wet road marking
$R_L(dry)$ is the retroreflectivity of the dry road marking
T is the texture factor
β is the luminance factor (the whiteness of the road marking material)

A, *B*, *C*, *D* are constants

If a constant (*A*, *B*, *C*, *D*) differs significantly ($p<.05$) from zero, the corresponding variable contributes to the uncertainty of the predicted value of $R_L(wet)$, and shall be included in the model. The hypothesis is that the model (1) gives predictions with better uncertainty than the model used so far, in which *MPD* was used instead of *T*. Therefore, also *MPD* is considered in the analysis.

The study is limited to profiled road markings, i.e. plane road markings using large glass beads for wet weather performance are not taken into account.

Initially, three important questions to be answered are:

1. Is the texture factor *T* a better predictor of $R_L(wet)$ than *MPD is*?
2. Do all four independent variables $R_L(dry)$, *T*, *MPD* and β correlate with $R_L(wet)$?
3. If so, can it be measured at speed?

The first question will give answer to the fundamental hypothesis:

The texture factor, *T*, is a better predictor of $R_L(wet)$ than *MPD* is.

The hypothesis and the three questions are discussed in Sections 4.1–4.3 and Chapter 5.

3. Field measurements

3.1. Measurement of dry and wet road marking retroreflectivity

Mobile measurement of dry road markings has been accomplished since the late 90's. There are at least four well-known instruments commercially available, but experience has shown that the LTL-M, manufactured by DELTA Light & Optics in Denmark, has the smallest uncertainty. A test of this instrument was carried out in 2010 (Lundkvist, 2010). This study showed that readings from LTL-M has an uncertainty of less than 4%, while another instrument (Ecodyn 30) showed uncertainty of approximately 10%.

With the results from the above mentioned study, and also, from several small validation tests, the LTL-M is to prefer. This means that if there is contribution from $R_L(dry)$ to the prediction of $R_L(wet)$, mobile measurement using the LTL-M will be carried out. Figure 1 shows a mobile measurement system using LTL-M and an optocator for measurement of the road marking profile.

Figure 1. Mobile measurement system registering the retroreflectivity and profile of road markings.

Even if mobile measurement is good enough, a hand-held measurement has an even better uncertainty. Therefore, when developing a prediction equation, readings of retroreflectivity from a hand-held instrument is to prefer. Thus, all readings below, except the road marking profile, are based on readings using hand-held instruments.

3.2. Measurement of the road marking profile

In the study mentioned in Chapter 1, the mean profile depth, *MPD*, was calculated from measurement of the road marking profile. The profile was measured at speed using an optocator mounted on the same vehicle that was equipped with the reflectometer, LTL-M.

In the study 2008, the correlation between $R_L(wet)$ and *MPD* was found to be reasonably good. However, there might be another texture measure which has an even higher correlation with $R_L(wet)$? In that case it would be possible to make predictions of $R_L(wet)$ with higher uncertainty.

Logically, the surfaces of the road marking profile that are aimed towards the driver should contribute most to the retroreflectivity, as the micro-beads will have no or poor function. Briefly, the profiled road marking has a number of small facets, of which some are oriented in the direction close to the incident and the reflected light. Each such facet contributes to the reflected luminous intensity to some degree, dependent on the area and orientation of the facet. The sum of the luminous flux from all facets will be a measure of the wet road marking visibility. More about the theory behind this is to be found in Annex A.

The texture factor, T, can be calculated from measurement of the road marking profile, using the same type of optocator as when calculating *MPD*. A method on how to calculate T is presented in Annex B.

3.3. Measurement of the luminance factor

There is no mobile instrument for measurement of road marking luminance factor, β, available. Probably, this type of measurement is difficult to carry out at speed. However, the variation of β is expected to be small within one type of road marking material. This means, that if there is a strong correlation between β and $R_L(wet)$, maybe a few number of hand-held readings would give sufficiently high uncertainty of β. But of course, mobile measurement would be to prefer.

4. Measurement instruments, methods and objects

In order to estimate the four constants *A, B, C* and *D* in Equation (1), the following measurements have been carried out:

- Retroreflectivity of dry road markings, $R_L(dry)$. Hand-held and mobile measurement using LTL-X and LTL-M, respectively. The model was developed from the hand-held readings.
- Retroreflectivity of wet road markings, $R_L(wet)$. Hand-held measurement using LTL-X.
- Luminance factor of dry road markings, β, Hand-held measurement using Konica Minolta Spectrophotometer CM-2500c.
- Profile of dry road markings, from which *MPD* and *T* were calculated. Mobile measurement using an optocator of type OPQ Systems RM-L1.

The optical instruments fulfil the requirements in EN-1436, while the optocator measures according to ISO 13473-1. Annexes 1 and 2 show the theory and calculation of the texture factor, *T*, respectively. However, *T* can shortly be described as the contribution to the retroreflection from all facets oriented in directions towards the driver.

In total, measurements were carried out at 56 spots. Approximately 18 hand-held readings were taken at each spot. However, objects No. 1–22 were applied in a test field and here three readings were taken on each road marking. The mobile instruments (LTL-M and the OPQ optocator) had a sampling frequency of x Hz.

In the study, only profiled road markings were included, i.e. flat markings and markings applied in a milled rumble strip were excluded. The measurement objects were in different state of wear, from brand new to worn road markings. The profile of the markings had different shapes, most of them of type longflex, dropflex or a type which has a profile almost like a stairway, see Figure 2.

Figure 2. Profiled road markings of type "grooved", "stairflex" and "combflex".

The measurements were carried out on five occasions as follows:

1. On road markings applied in a test field on road 35 in the district of Östergötland, Sweden. Measurements carried out in spring 2014. Observations 1–22.

2. On test road markings applied as edge lines on road 118 in the district of Skåne, Sweden. Measurements carried out in spring 2014. Observations 23–28.

3. On regular road markings on different roads in the districts of Småland and Östergötland, Sweden. Measurements carried out in autumn 2014. Observations 29–39.

4. On regular road markings on different roads in the districts of Småland and Östergötland, Sweden. Measurements carried out in spring 2015. Observations 40–52.

5. On regular road markings on different roads in the district of Sjælland, Denmark. Measurements carried out in autumn 2015. Observations 53–58.

The observation number refers to “No.” in the table of Annex C.

5. Results

5.1. Correlation analyses

Detailed results from the measurements are presented in Annex C. In this chapter is to be found the statistical analyses.

Table 1 shows the correlation between, on one hand $R_L(wet)$ and on the other hand $R_L(dry)$, T, MPD and β.

Table 1. Correlation coefficient, r, with significance level, p. Dependent variable is $R_L(wet)$.

variable	r	p
$R_L(dry)$	0.54	<0.001
T	0.59	<0.001
MPD	0.42	<0.005
β	-0.16	>0.05

Table 1 shows that there is no significant correlation between $R_L(wet)$ and β, which is due to the fact that the variance of β is small; all 56 materials have about the same whiteness. Consequently, β will be excluded from further analysis. The other variables, $R_L(dry)$, T and MPD show a positive correlation with $R_L(wet)$, which means that higher values of these variables imply higher value of $R_L(wet)$.

Furthermore, Table 1 indicates that T is a better predictor than MPD, as T has better correlation with $R_L(wet)$ than MPD has.

Before continuing the analysis, the results of each measurement site should be evaluated. Are the results homogenous over test site? Table 2 and 3 show average values and the slope in the regression analyses at the five test sites, respectively.

Table 2. Average values of four variables on five test sites.

Test site	$R_L(dry)$	T	MPD	$R_L(wet)$
1	110	0.068	1.09	12
2	173	0.206	1.26	25
3	187	0.097	0.93	26
4	201	0.094	0.71	13
5	148	0.175	1.14	24

Table 3. Slope of the regression line of four variables on five test sites. Dependent variable is $R_L(wet)$.

Test site	$R_L(dry)$	T	MPD
1	0.095	85	1.0
2	0.240	84	19.6
3	0.093	-28	9.5
4	0.073	152	28.0
5	0.227	131	44.1

It must be stressed that at test sites 2 and 5 there were only 6 and 5 observations, respectively. That means that the results are extremely sensitive to an outlier – an observation that deviates from the regression line more than two standard deviations. Anyway, from Table 3 let us note that the slope of *T* at site 3 has a negative sign, whilst the slope is positive at the other sites.

5.2. Regression analyses

As said before, the number of observations is small on two test sites and one should not draw far-going conclusions from the results in Tables 2 and 3. However, considering three regression analyses, using the whole data material (56 observations); one analysis with independent variable $R_L(dry)$, one with *T* and one with *MPD*, the output shows three outliers in all three analyses: Observations No. 2, No. 34 and No. 57. Regarding the independent variable *T*, also observation No. 33 is an outlier. The fact that three independent variables all have the same three outliers is a strong indication on a discrepancy in the dependent variable, $R_L(wet)$ for these observations. The three regression analyses are shown in Figure 3.

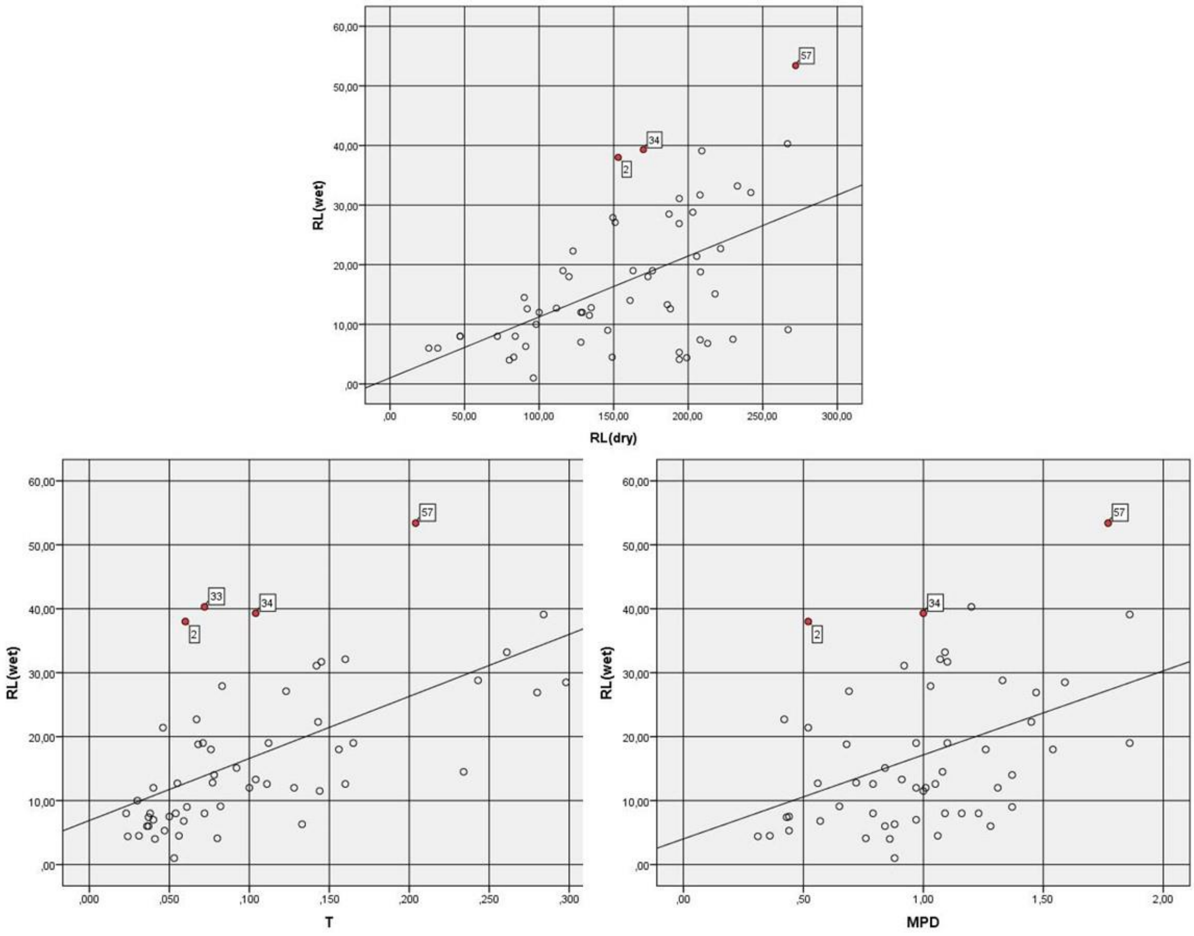

Figure 3. Red marked outliers in three regression analyses.

If the outliers are included in the analysis, a stepwise multiple regression analysis includes both $R_L(dry)$ and T:

$$R_L(wet) = -2 + 0.073 \cdot R_L(dry) + 77 \cdot T \quad (2),$$

with the correlation coefficient r = 0.69 and a 90% prediction interval ± 14.1 mcd/m^2/lx.

If the outliers are rejected, the result of the corresponding analysis is:

$$R_L(wet) = 0.043 \cdot R_L(dry) + 83 \cdot T \quad (3),$$

with the correlation coefficient r = 0.77 and a 90% prediction interval ± 10.2 mcd/m^2/lx.

With the rejection of the outliers, the regression coefficient of $R_L(dry)$ decreased from 0.073 to 0.043. This fact indicates that glass beads have a high influence on the dependent variable, $R_L(wet)$, on objects No. 2, 33, 34 and 57, which justifies the rejection of those outliers. Or maybe these road markings were not wetted properly before measurement, or the time between wetting and measurement was too long.

Figure 4 shows the relationship between predicted and measured values of $R_L(wet)$, using Equation (3).

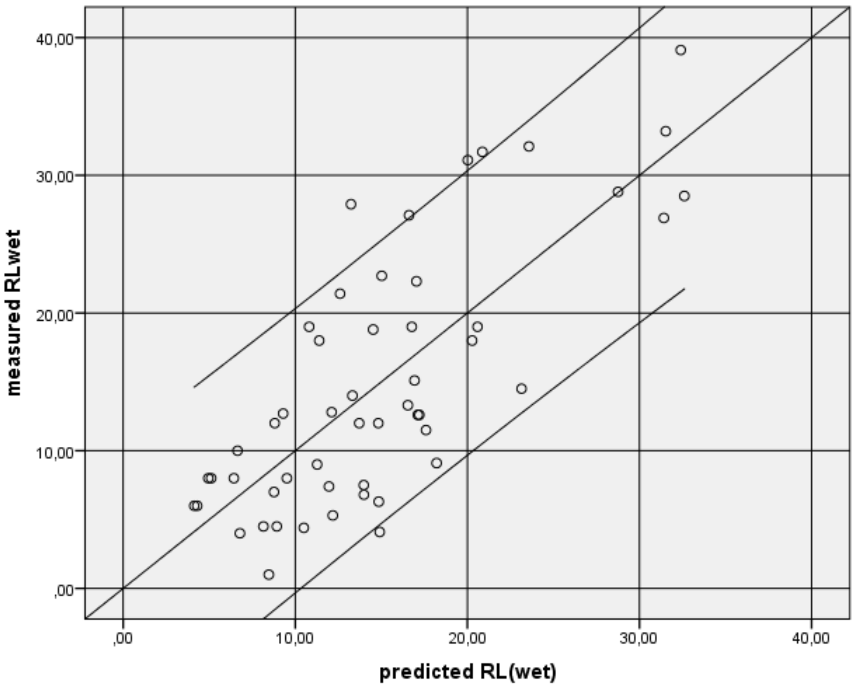

Figure 4. The relationship between predicted and measured values of $R_L(wet)$ including a 90% prediction interval for individual observations.

So far (2015), an equation using $R_L(dry)$ and *MPD* has been used for prediction of $R_L(wet)$. With use of the same data set which Equation (3) is based on, a regression analysis shows:

$$R_L(wet) = -12 + 0.090 \cdot R_L(dry) + 14 \cdot MPD \quad (4),$$

With r = 0.70 and a 90% prediction interval ± 13.4 mcd/m^2/lx.

The results of Equation (3) and Equation (4) show that the exchange of *MPD* to *T* means an improvement of the uncertainty of the predictions.

5.3. Uncertainty and validation of the model

The uncertainty of the predictions, calculated as

$$\varepsilon_{unc} = \frac{\left|R_{L,wet,pred} - R_{L,wet,measured}\right|}{n}$$

is estimated being 5.0 mcd/m^2/lx or 33.6%. This is an improvement from 5.6 mcd/m^2/lx when using *MPD* as the texture measure. The standard deviations of the residuals were 6.02 and 6.72 mcd/m^2/lx when using *T* and *MPD*, respectively. This in turn meant that the 90% prediction intervals were ± 10.2 and 13.4 mcd/m^2/lx.

The estimation of the uncertainty can be seen as a cross-validation of the model. This validation is not ideal, as it uses data whereupon the model has been developed. A more strict validation needs a new set of data, which hopefully can be collected during 2016.

6. Discussion and conclusion

One purpose of the study was to answer the three questions in Chapter 2:

1. Is the texture factor *T* a better predictor of $R_L(wet)$ than *MPD* is?

   Yes, the texture factor improves the uncertainty of the prediction of $R_L(wet)$.

2. Do all four independent variables $R_L(dry)$, *T*, *MPD* and β correlate with $R_L(wet)$?

   β has no significant correlation with $R_L(wet)$. The other three independent variables show a positive, significant correlation.

3. If so, can it be measured at speed?

   Yes, the independent variables of interest can be measured at speed.

Consequently, the study has shown that the fundamental hypothesis is accepted: The texture factor, *T*, is a better predictor of $R_L(wet)$ than *MPD* is.

The answers on the three questions above indicate that the outcome of the study has been great. However, the improvement of the uncertainty was not as good as could be expected. Still the uncertainty of a prediction is on average 5.0 mcd/m^2/lx, which corresponds to almost 34%. A small study in Denmark (Lundkvist, 2004) has shown that the hand-held measurements of $R_L(wet)$ have a repeatability of ε_{rep} = 12.7%. As the predictions are based on hand-held measurement and $\varepsilon_{unc}^2 = \varepsilon_{prec}^2 + \varepsilon_{rep}^2$, one can estimate the precision of the predictions being 31.3% or 4.7 mcd/m^2/lx.

Regarding the sample of objects included in the study, the average value of $R_L(wet)$ is 16.9 mcd/m^2/lx. This performance value is low, as the requirements in the Nordic countries are 25 or 35 mcd/m^2/lx. However, this reflects the reality; the road marking retroreflectivity in wet condition is poor; at least in Denmark and Sweden.

There may be two effects which contribute to the retroreflectivity of the wet road marking.

a) The reflection in the facets that are oriented in directions towards the driver. This effect is handled by the texture factor *T*.

b) If there are working micro beads, also the retroreflectivity of these beads will contribute. So far, the estimate of this effect has not been solved.

Thus, the micro beads of the surface of the road marking may have contributed to the retroreflectivity of some markings, not of others. If the beads contribute, this *might* have been due to measurement error: If the time between wetting and reading is too long on a hot day, the surface may be humid, but not really wet. However, this is probably not the case in our study: Even on the warmest day of measurement, the 27th of August 2014, the temperature never exceeded 20°C. Therefore, it is more likely that the influence of the micro beads is dependent of the inclination and wear of the road marking profiles. A reasonable hypothesis is that on an almost vertical surface the water runs off the surface, thus making the beads appearing. If this fact is considered in the model, there should be a good chance to increase the precision of the predictions. Attempts to correlate the inclination with $R_L(wet)$ have been done, however so far without success.

One important question arises: Has this study reached the goal? In other words: Is the new model useful and should it replace the old model which uses *MPD* instead of *T*? There is no doubt that the old model should be replaced some time. However, it might be too early, taking in account the number of data that the new model is based on. Therefore, even if the new model has a better predictive value than the old one, the suggestion is to collect more data in order to determine the constants in Equation (3) with better accuracy. Maybe data from a planned state-of-the-art study in the Nordic countries could be used.

Finally, within this study the different actions of the project have been accomplished: Theoretical considerations, static and mobile measurements, analysis and documentation. However, one cannot say that the final goal was reached: There was a hope to improve the predictions even more. Therefore, although the present study answered important questions, the suggestion for the future is:

Use the state-of-the-art measurements in the Nordic countries which will be accomplished in 2016 for improvement and validation of the new prediction model.

References

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Annex A

The texture factor T of a road marking surface

A.1 Introduction

The coefficient of retroreflected luminance R_L is introduced in A.2 together with the 30 m geometry of measurement. Both are defined in EN 1436 “Road marking materials – Road marking performance for road users”.

R_L is defined by L/E, where L is the luminance of the measured field on the road marking surface and E is the illuminance at the field measured on a flat perpendicular to the direction of illumination.

In A.3 it is shown that R_L can be expressed by $R_L = G\times(I/\Phi)$, where G is a geometrical factor with a fixed value of 0,542 for the 30 m geometry. Therefore, R_L values can be measured and evaluated by means of the ratio I/Φ, where I is the luminous intensity of light reflected into the observation direction from the field and Φ is the luminous flux falling on the field.

In A.4 the road marking surface is described by a subdivision into small facets each attributed an area ΔA and an orientation given by the normal to the area. It is shown that I/Φ can be expressed by $q\times T$, where q is a suitable constant or average luminance coefficient of the illuminated parts of the road marking surface and T is a texture factor. In accordance with this, R_L can be expressed by $R_L = G\times q\times T$.

The value of T is a weighted average value of cos(u), where u is the angle between the normal of the facet and the direction of observation. The weight given to each facet is $\cos(v)\times\Delta A$, where v is the angle between the normal and the direction of illumination. Accordingly, T shows on a scale from 0 to 1 to what degree the facets on the average face the observation direction.

In A.5 it is assumed that the facets have diffuse reflection, so that the expression for R_L can be converted to $R_L = G\times T\times\rho\times 1000/\pi$, where ρ is the reflectance and the factor of 1000 is introduced in order to convert the unit from $cd\cdot m^{-2}\cdot lx^{-1}$ to the 1000 times smaller unit of $mcd\cdot m^{-2}\cdot lx^{-1}$.

This predicts a maximum R_L value of 172,5 and realistic R_L values for surface reflection of perhaps 60 $mcd\cdot m^{-2}\cdot lx^{-1}$. It is pointed out that R_L values of dry road markings are mostly higher, or much higher, because of amplification of the reflection in the surface by the use of glass beads.

The wet condition is considered in A.6. It is well known that the action of glass beads is strongly reduced, or even completely lost, when the surface is covered by a thin water film. The contributions from facets with small inclinations are strongly reduced because of reflections in the water film in the two passages of light both in and out of the water surface. The contributions from facets with large inclinations, on the other hand, are not strongly reduced. The effect is that road markings with profiles or structures can provide valuable R_L values for the wet condition of for instance 30 $mcd\cdot m^{-2}\cdot lx^{-1}$.

A.2 The coefficient of retroreflected luminance R_L and the 30 m geometry of measurement

The ability of the field of the road marking surface to reflect the incoming light is measured by the coefficient of retroreflected luminance R_L defined by:

$R_L = L/E$

where L is the luminance of the field,

and E is the illuminance at the field measured on a flat perpendicular to the direction of illumination.

In accordance with EN 1436, R_L values are to be measured or determined for the 30 m geometry with an angle of illumination ε of 1,24° and an angle of observation (measurement) α of 2,29°. The two angles are measured from the directions of illumination and observation to the flat of the road marking surface and the two directions lie in the same vertical flat.

The luminance of a field is given by:

$L = I/(A \times \sin(\alpha))$

where L is the luminance of the field,

I is the luminous intensity of light reflected from the field into the direction of observation,

A is the area of the field,

and multiplication with $\sin(\alpha)$ serves to project the area of the field into the direction of observation.

A.3 The geometrical factor and its constant value

The incoming luminous flux on the measured field is given by:

$\Phi = E \times A \times \sin(\varepsilon)$

where Φ is the incoming luminous flux,

and multiplication with $\sin(\varepsilon)$ serves to project the area of the field into the direction of ilumination.

Consequently, R_L can be determined by:

$R_L = I/(A \times \sin(\alpha))/(\Phi/(\sin(\varepsilon) \times A)) = (I/\Phi) \times (\sin(\varepsilon)/\sin(\alpha)) = G \times (I/\Phi)$

where $G = \sin(\varepsilon)/\sin(\alpha)$ is a geometrical factor.

The geometrical factor G has a constant value of 0,542 for the 30 m geometry. Therefore, R_L values can be measured and evaluated by means of the ratio I/Φ.

A.4 The texture factor

A road marking surface is assumed to have texture, and in some cases profiles or other structures. The geometry of the surface can be thought of as composed of small flat facets each with a small area and a certain orientation given by the direction of its normal.

A facet will be illuminated, if it faces the direction of illumination and if it is not in the shadow from other facets. If so, the incoming luminous flux on the facet is:

$\Delta\Phi = E\times\Delta A' = E\times\cos(v)\times\Delta A$

where $\Delta\Phi$ is the incoming luminous flux,

$\Delta A'$ is the area of the facet as projected into the direction of illumination,

and v is the angle between the normal of the facet and the illumination direction.

The total luminous flux falling on the facets is given by:

$\Phi = \Sigma\Delta\Phi = E\times\Sigma\Delta A' = E\times\Sigma(\cos(v)\times\Delta A)$

where Σ implies summation for all illuminated facets.

The reflected luminous intensity from the facet back into the direction of observation is:

$\Delta I = q\times\cos(u)\times\Delta\Phi = q\times\cos(u)\times E\times\cos(v)\times\Delta A$

where ΔI is the reflected luminous intensity,

u is the angle between the normal of the facet and the observation direction,

and q is the luminance coefficient of the surface of the facet.

For a field of the road marking, the total reflected luminous intensity is:

$I = \Sigma\Delta I = E\times\Sigma(q\times\cos(u)\times\cos(v)\times\Delta A)$

where Σ implies summation for all illuminated facets.

Please note that the summation of ΔI for all illuminated facets reflects an assumption that all illuminated facets are visible in the direction of observation. This is a reasonable assumption, as the direction of observation lies above the direction of illumination.

For the time being, it is assumed that q has a constant value – or is represented by a suitable average value. This would make I represented by:

$I = E\times q\times\Sigma(\cos(u)\times\cos(v)\times\Delta A)$

Finally, R_L is expressed by:

$R_L = G\times(I/\Phi) = G\times E\times q\times\Sigma(\cos(u)\times\cos(v)\times\Delta A)/(E\times\Sigma(\cos(v)\times\Delta A)) = G\times q\times T$

where T is a texture factor with a value given by $T = \Sigma(\cos(u)\times\cos(v)\times\Delta A)/\Sigma(\cos(v)\times\Delta A)$.

The expression for T shows that T is a weighted average of cos(u) and thus without dimension. It is on a scale from 0 to 1 and shows to what degree the facets on the average face the observation direction.

However, there is a small simplification based on the matters that the directions of illumination and observation are close to each other, and that it is mainly facets with significant values of cos(v) that contribute to the value of cos(u). The simplification is that cos(u) and cos(v) can replace each other, so that T can as well be calculated by:

$T = \Sigma(\cos^2(v)\times\Delta A)/\Sigma(\cos(v)\times\Delta A)$

A.5 R_L values provided by reflection in the surface

The expression for R_L is extraordinary simple. Under the further assumption that the facets have diffuse reflection, q can be expressed by:

$q = \rho \times 1000/\pi$

where ρ is the reflectance on a scale from 0 to 1,

and the factor of 1000 is introduced in order to convert the unit from $cd \cdot m^{-2} \cdot lx^{-1}$ to the 1000 times smaller unit of $mcd \cdot m^{-2} \cdot lx^{-1}$ that is used by convention.

The expression for the R_L value is then modified to:

$R_L = G \times T \times \rho \times 1000/\pi$

With the above-mentioned fixed value of 0,542 for G and the maximum values of 1 for T and ρ, the maximum R_L value becomes 172,5 $mcd \cdot m^{-2} \cdot lx^{-1}$.

In practical conditions, when the road marking is dry, the values may be for instance 0,5 for T and 0,7 for ρ leading to R_L values of for instance 60 $mcd \cdot m^{-2} \cdot lx^{-1}$. In practice the R_L value is mostly higher, or much higher, because of amplification of the reflection in the surface by the use of glass beads.

A.6 The wet condition

By the wet condition is meant the wet condition defined in EN 1436 (pour ample water on the road marking and wait 60 seconds).

In the wet condition, the surface is covered by a water film, which has to be passed twice, first for the incoming light and then for the reflected light. In each of these passages, there is a loss of light by surface reflection in the water surface, causing a reduction of the R_L value.

This loss may be accounted for in more than one way, for instance by introducing an additional factor in the expression for R_L or by reducing the value of the luminance coefficient. However, it is more practical to account for this loss by a reduction of the T value, as the loss in each of the facets depends on the orientation of the facet and, therefore, can be considered together with the values of cos(u) and cos(v).

The value of T is then to be calculated by means of:

$T(wet) = \Sigma(W \times \cos^2(v) \times \Delta A)/\Sigma(\cos(v) \times \Delta A)$

where T(wet) indicates the T value for the wet condition,

and W is a factor for loss in the water film.

In order to derive the loss during the first passage of the water film, the reflectance of the water film R can be calculated by means of the Fresnel equation using a refractive index for water of 1,33 and the value of the angle v as the angle of incidence. The loss factor for the first passage is then 1-R.

The loss during the second passage of the water film should in principle be calculated in the same manner, using the value of the angle u as the angle of incidence. However, in practice the total loss can be represented by $W = (1-R)^2$.

The value of R is illustrated in figure A.1 and of W in figure A.2.

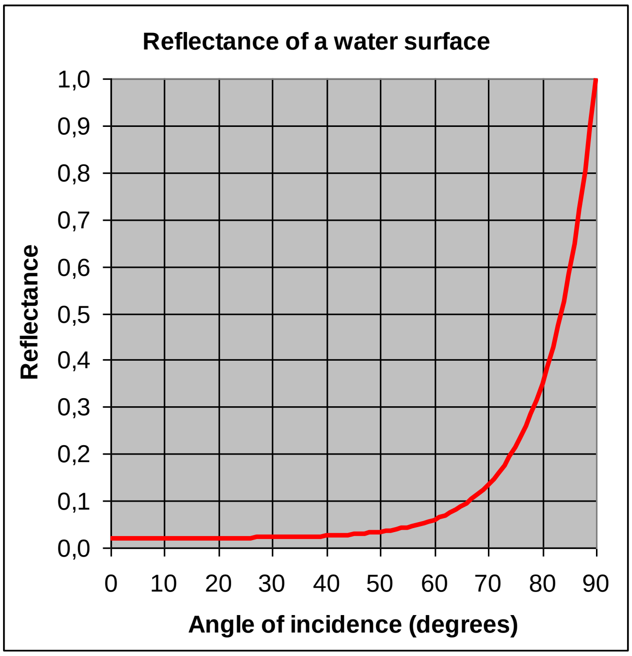

Figure A.1: Reflectance R by a single passage into a water film.

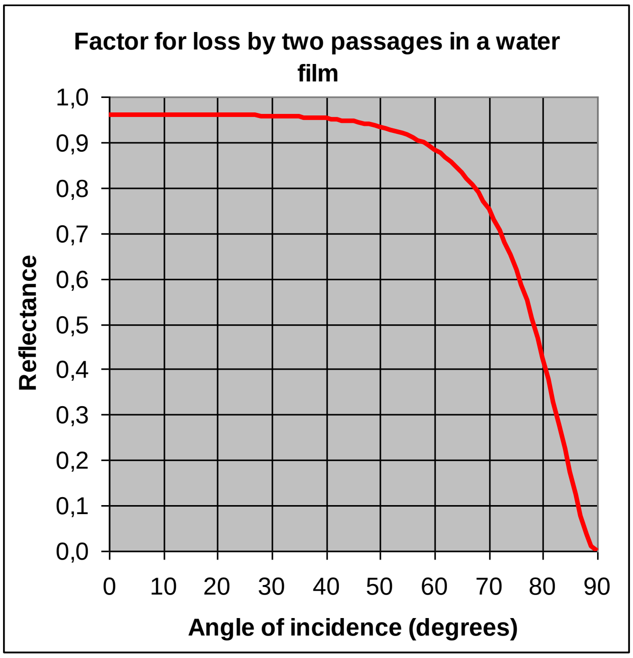

Figure A.2: Loss factor W by two passages through a water film.

Figure A.2 implies a large loss, when the angle of incidence on a facet is large. Such facets are numerous, when the T value for the dry condition is small in itself, which is typical for road markings without profiles or other structures.

Surfaces with profiles or structures, on the other hand, have T values for the dry condition that are for the most part made up by the contributions from facets with large inclinations and are larger than for markings without profiles or other structures. The contributions from facets with large inclinations are reduced by some in the wet condition, but not by much. Additionally, contributions from facets with small inclinations are reduced strongly, but these are already small.

Accordingly, values of T(wet) are very small for road markings without profiles or other structures, while the values of T(wet) can be significant for road markings with profiles or other structures. This indicates that road markings of the first-mentioned type do not provide any significant contribution to the R_L value by surface reflection, while road markings of the last-mentioned type may do so.

Simultaneously, the action of glass beads is mostly strongly reduced or lost completely in the wet condition, because of being partly covered by the water film.

The two matters together explain why road markings without profiles or other structures have very low R_L values in the wet condition, typically 0 to 5.

Road markings with profiles or other structures may, on the other hand, have R_L values in the wet condition of for instance 30 $mcd \cdot m^{-2} \cdot lx^{-1}$. This is not much, but does contribute to the performance in the wet condition.

It seems also that the action of glass beads is not completely lost for some road markings, which have profiles or structures that leave positions for glass beads on surfaces with strong inclinations. For such road markings, R_L values in the wet condition may be for instance 50 $mcd \cdot m^{-2} \cdot lx^{-1}$.

Annex B

Method for the calculation of the texture factor T of a road marking surface from a measured profile

B.1 Introduction

By method of calculation is meant the sum of the methods described in this annex implemented in software of one form or another. The actual implementation so far has been in an excel file, which has sheets for:

- Input and results,
- Profile data,
- Correction of indicator,
- Ranges of profile to include,
- Calculation of T.

The user has to dump the profile data into three columns in the sheet “Profile data” and then to use the sheet “Input and results”. The other sheets contain calculations only.

B.2 accounts for the expression of the value of the coefficient of retroreflected luminance R_L by factors, of which one is the texture factor T. The account is a summary from annex A, to which reference is made for details.

In B.3 it is explained how the geometry of a road marking surface is represented by a profile measured in a scan with a vehicle mounted optocator. The profile has a number of points in an (x,y) coordinate system, where x refers to the distance along the road and y refers to the height of the point. It is assumed that any profile or other structure in the road marking surface lie essentially transverse to the road marking, so that facets can be represented by the line segments between neighbouring points. Accordingly, the area of a facet is represented by the length of the line segment.

B.4 introduces a procedure for determining if a facet is illuminated, and if so for calculating the fraction that is illuminated.

B.5 accounts for situations where points in a profile can be recorded on the black road surface instead on the white road marking surface.

In order to distinguish between these situations, a profile is associated with an indicator with a value 0 or 1 for respectively black and white for each point in the profile. It is explained that this indicator is not completely reliable and needs to be supported by other criteria, and also to be shifted a number of steps along the profile.

Further, three optional values of T are provided, each of which may be relevant for different situations or to avoid use of the above-mentioned indicator. Even further, two optional methods are provided for limiting the parts of the profile that are to be included in the calculation of T.

For further assistance, a diagram showing the profile with indications of white/black and illuminated/not illuminated for each point is provided.

B.6 deals with uncertainty of measurement of the heights in a profile. It is explained that uncertainty can cause false predictions of T values and thereby false predictions of R_L values for road markings without profiles/structures. However, a simple method to avoid this is accounted for.

B.7 provides a discussion of road markings with round structures and concludes that T values will be too high, but not by much.

An example of the sheet for input and results is illustrated and discussed in B.8.

B.2 The R_L value expressed by factors

In annex A it is explained that the contribution by the road marking surface to the coefficient of retroreflected luminance R_L in the unit of $mcd \cdot m^{-2} \cdot lx^{-1}$ can be calculated by:

$R_L = G \times T \times \rho \times 1000/\pi$,

where G is a geometrical factor with a fixed value of 0,542 for the standard 30 m measuring geometry,

T is a texture factor,

and ρ is the reflectance of the road marking surface.

The value of T can be calculated by subdividing the road marking surface into small facets each attributed with an area ΔA and an orientation given by the normal to the area.

For the dry condition, this expression applies:

$T(dry) = \Sigma(\cos^2(v) \times \Delta A))/\Sigma(\cos(v) \times \Delta A)$

where Σ implies summation over all the illuminated facets,

and v is the angle of light incidence on a facet measured between the normal to the area and the direction of illumination,

and ΔA is the area of each facet.

For the wet condition, an additional loss factor is introduced leading to this expression:

$T(wet) = \Sigma(W \times \cos^2(v) \times \Delta A)/\Sigma(\cos(v) \times \Delta A)$

where T(wet) indicates the T value for the wet condition,

and W is a factor for loss in the water film.

The loss factor accounts for losses by reflections in a water film in two passages of light both in and out of the water surface. It can be calculated by:

$W = (1-R)^2$

where R is the reflectance for surface reflection in a water film as calculated by means of the Fresnel equation.

The refractive index needed for the calculation of R can be set to 1,33.

The method allows a choice between the dry and the wet condition. However, in the context of this report, only the wet condition is interesting.

B.3 Representation of the road marking surface by a profile

The geometry of a road marking surface is represented by a profile measured in a scan with a vehicle mounted optocator. The profile has a number of points (x_1, y_1), (x_2, y_2), (x_3, y_3) ... (x_N, y_N), where x refers to the direction along the road marking, y refers to the height and N is the total number of points. This is illustrated in figure B.1.

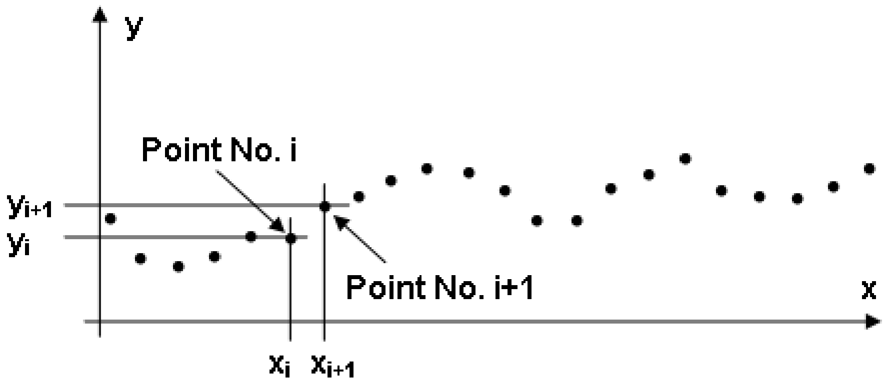

Figure B.1: Points in a profile.

It is assumed that any profile or other structure in the road marking surface lie essentially transverse to the road marking, so that a facet No. i is defined by the two points (x_i,y_i) and (x_{i+1},y_{i+1}). Refer to figure B.2.

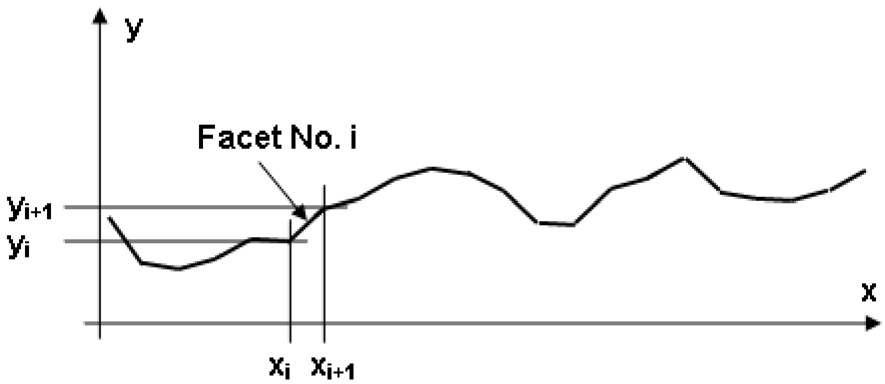

Figure B.2: A facet defined by two points in a profile.

The length of this facet is given by $L_i = \sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2}$, while the angle of incidence is given by $v = 90^0 - \arctan((y_{i+1} - y_i)/(x_{i+1} - x_i)) - \varepsilon$.

B.4 Illumination of facets

There are two conditions that a facet is illuminated:

a. the angle of incidence v must be larger than 0°,
b. the facet must not be in the shadow of facets in front.

The first condition is easily evaluated, once v has been calculated as accounted for in the above.

The second condition is evaluated by means of a shadow line defined by a shadow height S_i that is initially set to $S_1 = y_1$ for i=1 and is updated at point i+1 in this way:

- The shadow height at point i+1 is set to $S_{i+1} = S_i - \tan(\varepsilon) \times (x_{i+1} - x_i)$,
- If S_{i+1} is smaller than y_{i+1}, then set S_{i+1} to y_{i+1} else keep the value.

This process of updating is carried out for all the facets until the last facet at i = N-1.

Figure B.3 illustrates how the shadow line progresses with downward slope given by the illumination angle ε, but is shifted up to the top points of facets that it meets. Facets or parts of facets that are illuminated, are marked by red.

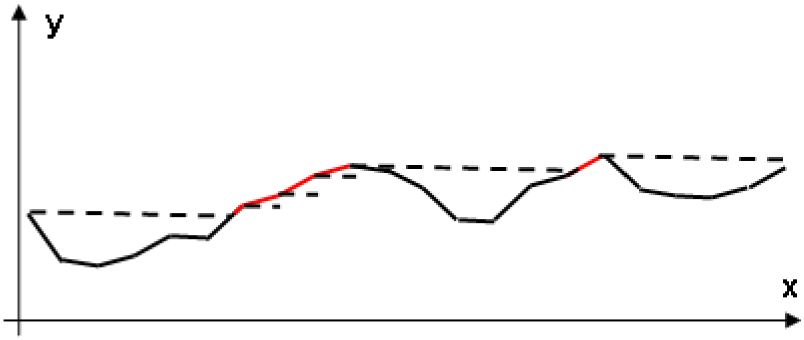

Figure B.3: Progression of the shadow line.

At each facet, the illuminated fraction F_i of the facet is determined this way:

- If S_{i+1} is larger than or equal to y_{i+1}, the facet is entirely in the shadow and the fraction F_i is set to $F_i = 0$.
- If S_{i+1} is smaller than or equal to y_i, the facet is illuminated over its entire length and the fraction F_i is set to $F_i = 1$.

For cases in between the two above-mentioned cases, the facet is illuminated over some of its length and the fraction is calculated by: $F_i = \dfrac{S_i - y_i}{(y_{i+1} - y_i) - (S_{i+1} - S_i)}$.

In the calculation of T, the illuminated area of the facet ΔA is to be replaced by the illuminated length given by $F_i \times L_i$. Further, the projected illuminated area A' is to be replaced by a projected length L'.

The value of cos(v) is derived using the value of v calculated as described in the above.

B.5 Distinction between the road surface and the road marking surface

The above is sufficient, when the profile is on white parts of the road marking surface only, or when black parts of the road surface between profiles are included, but not illuminated. However, illuminated parts of the road surface may be included in the profile in these situations:

a. profiles are worn to a degree that allows illumination of the road surface in between the profiles,
b. the road marking is eroded to a degree that the road surface beneath the road marking has emerged in places,
c. the road marking is a broken line,
d. the driver of the measurement vehicle has not been able to keep the optocator over the road marking so that the profile includes the road surface over some length,
e. any combination of the above.

In order to handle these situations, each point in the profile is associated with an indicator with the possible values 0 and 1, meaning that the point is recorded on respectively the road surface or the road marking. The value is selected on the basis of the signal strength of the optocator.

In the cases a. and b., facets with point indicators 0 for black should be included in the sum in the denominator in the expressions for T, but not in the sum in the nominator. The reason is that the denominator accounts for the incoming luminous flux, while the nominator accounts for the luminous intensity of reflected light.

In the cases c. and d., facets with point indicators 0 for black should not be included in any of the sums, neither for the nominator nor the denominator. The reason is that this excludes the road surface, which is irrelevant in these cases, from the T values.

However, the indicator is not completely reliable. As an example, the value 0 appears even when the point is clearly on white road marking material, but for instance at some depth in profiles or structures. The method includes a filter, that changes indicator from 0 to 1, when 0 is obviously wrong. This, however, does not eliminate the problem.

Therefore, the method provides three optional values of T:

I. all facets are included, ignoring the indicator values, as if all points are on the road marking,
II. facets with point indicators 0 for black are excluded from the sums of both the nominator and the denominator,
III. facets with point indicators 0 for black are included in the sum in the denominator, but excluded from the sum in the nominator.

Option I can be used, when there is reasonable certainty that the profile covers only white road marking surfaces. This purpose is to exclude the influence of erroneous indications with 0.

Option II can be used in the above-mentioned cases c. and d., when there is reasonable certainty that the road marking is not so eroded that the cases a. and b. apply simultaneously.

Option III can be used in the above-mentioned cases a. and b., when the cases c. and d. do not apply simultaneously.

This shows that the options I, II and III do not cover all the cases. For this reason, another feature has been added to the method, which is to include only some of the profile in the calculations. The options are:

A. to decide on a range of distances to include, giving both ends of the range as input values,
B. to let the method itself determine the ranges of distances, in which the profile covers white road marking material.

Option A is suitable when for instance the driver of the vehicle has missed the road marking at the front or back end of the scan. However, option A has wider use, for instance to select one or more ranges, followed by averaging the T values for the individual ranges by hand.

Option B is convenient when the road marking is broken. If so, the method provides the number of line segments, and an estimation of the length of the line segments and their spacing (the sum of the length and the length of the gap between line segments). The estimated values are correct only, when the method identifies all of the line segments. However, option B also has wider use, for instance when the driver of the vehicle has missed the road marking in one or more parts of the scan.

This feature can be used to handle the cases c. and d., so that the choice between options I, II and III becomes more simple. In practice, the choice stands between option I, when there is reasonable certainty that the selected part of the profile covers only white road marking, or option III, when the road marking is worn or eroded.

The method includes a diagram of the profile, in which the following four cases are indicated by the colour of the points:

- Points indicated as white, and illuminated
- Points indicated as white, not illuminated
- Points indicated as black, and illuminated
- Points indicated as black, not illuminated

This diagram is helpful for the choice of the above-mentioned options.

There is another problem with the indicator, that the indication of 1 for white has a delay, which is caused by a need for some integration time of the detector system of the optocator. The delay is sufficient to make the indication change from black to white a number of points after the profile has actually entered the white road marking. This tends to cause a significant reduction of the T value, as the good contributions to the T value from the fronts of road markings are omitted.

Therefore, the method has been equipped with a facility that moves all the indications a number of steps back in time (from right to left in the diagram). The number of steps is an input value, that should be selected so that the fronts of profiles/structures become marked as white in the diagram. This normally happens when the number of steps is set to a value in the range from 10 to 20.

B.6 Uncertainty of measurement of the profile heights

T(wet) values of flat road markings tend to be not very small, which leads to the prediction that such road markings have significant R_L values in the wet condition. This is in contradiction to the general experience that flat road markings have R_L values in the wet condition that are very small or even zero.

The reason seems to be random variation of the y value from point to point in the profiles. This is assumed to be caused by measuring uncertainty with a standard deviation of approximately 0,07 mm. With a distance between points of 0,8 mm, this uncertainty leads to an uncertainty of the slope of facets with a standard deviation of 0,124. Cases can occur with twice this slope, i.e approximately 0,25. Such slopes actually lead to significant values of T(wet).

For this reason the measured y values are not used directly. Instead the method has a simple facility to replace the y value at a particular point No. i by the average of the measured y values at the points No. i-1, i and i+1. This reduces the standard deviation of the measuring uncertainty from 0,07 mm to $0{,}07\ \sqrt{3}$ mm equal to approximately 0,04 mm. Slopes to be expected are, therefore, reduced to approximately 0,14.

When considering these slopes, it should be taken into account that contributions to T(wet) depend strongly on the slope. One matter is that cos(v) is approximately in proportion to the slope and is summed up with the power of 2. Another matter is that loss factor W also increases strongly with the slope.

The averaging of three y values causes, therefore, a strong reduction of the contribution by uncertainty of measurement to T(wet) values for flat road markings. The reduction is at least by a factor of 5, which solves the problem.

It should be pointed out that the T(wet) values of road markings with profiles/structures are not affected much by the averaging of three y values. The main reason is that such road markings have facets on front sides with large slopes, that provide the main contributions to T(wet), and that these contributions are not affected much by relatively small changes of the slopes of facets – at least not on the average.

B.7 Road markings with round structures

In B.3 it is assumed that any profile or other structure in the road marking surface lie essentially transverse to the road marking. This is a valid assumption for most types of road markings with profiles/structures, but not for a road marking with round structures as illustrated in figure B.4.

In such a road marking, different transverse locations of scans will lead to different profiles. The two extreme cases are indicated in figure B.4

Scan 1 is over the middle of a row of round structures, the profile is illustrated in figure B.5. This scan will provide a fairly large T(wet) value, because the profile has a large spacing that allows the light to penetrate deep down where slopes are large. A large T(wet) value is also realistic, as the profile is actually complying with the above-mentioned assumption.

Scan 2 is in between two rows of structures, the profile is illustrated in figure B6. This scan will provide a fairly small T(wet) value, because the profile has a small spacing that does not allow the light to penetrate deep down. Even if this T(wet) value is fairly small, it is too high, because the light meets facets that do not face the illumination direction.

In practice the driver of the vehicle cannot stay accurately at the same position relative to a road marking, so that a long profile will show both cases and all cases in between. The conclusion is, therefore, that the T(wet) value derived from a long scan will be too high. However, the value will not be much too high, as it is the small contributions that are too high, while the large contributions are realistic.

For this reason, road markings with round structures are handled in the same way as other road markings. Additionally, it would be difficult to provide a more realistic calculation of T(wet) values for road markings with round structures. An analysis of some simple cases indicate that the T(wet) values can be too high by up to 20%.

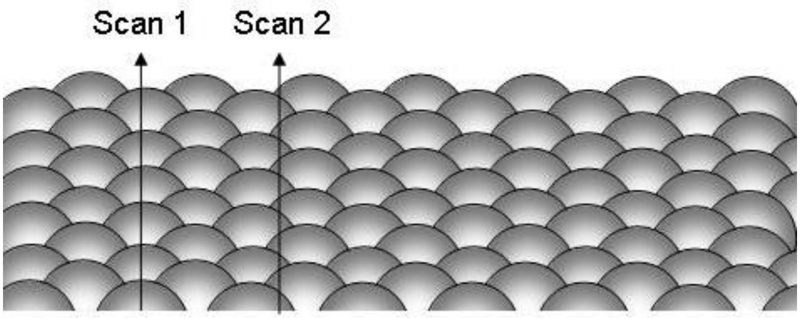

Figure B.4: A road marking with round structures.

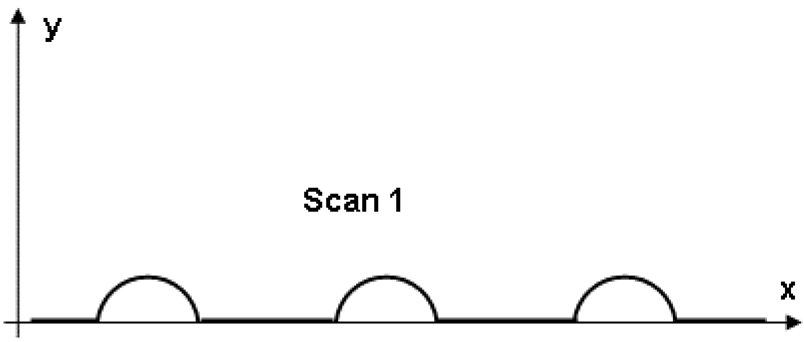

Figure B.5: The profile in one scan of the road marking.

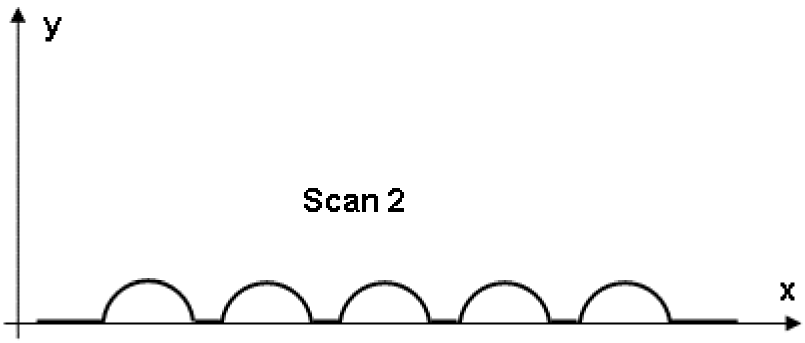

Figure B.6: The profile in another scan of the road marking.

B.8 Input and results

Figure B.7 shows an example of the sheet for input and results for the method as implemented in an excel file. The road marking is a broken line and accordingly option B for a broken line as described in B.5 has been selected.

The road marking has a pattern of grooves; this is clearly visible in the diagram with a height of approximately 2 mm. This matter and a high R_L value for the dry condition of 267 mcd·m^{-2}·lx^{-1} shows that the road marking is in a good condition. Accordingly, the indications of black for points within the line segments (either black or yellow points in the diagram) are considered to be false, and the T(wet) value of 0,072 of option I as described in B.5 should be selected.

This value of T(wet) indicates a contribution by surface reflection to the R_L value for the wet condition of 8 to 9 mcd·m^{-2}·lx^{-1}. However, this road marking is clearly a candidate for having active glass beads in protected positions in the grooves and a higher R_L value for the wet condition should be expected. The actual measured value is 40 mcd·m^{-2}·lx^{-1}.

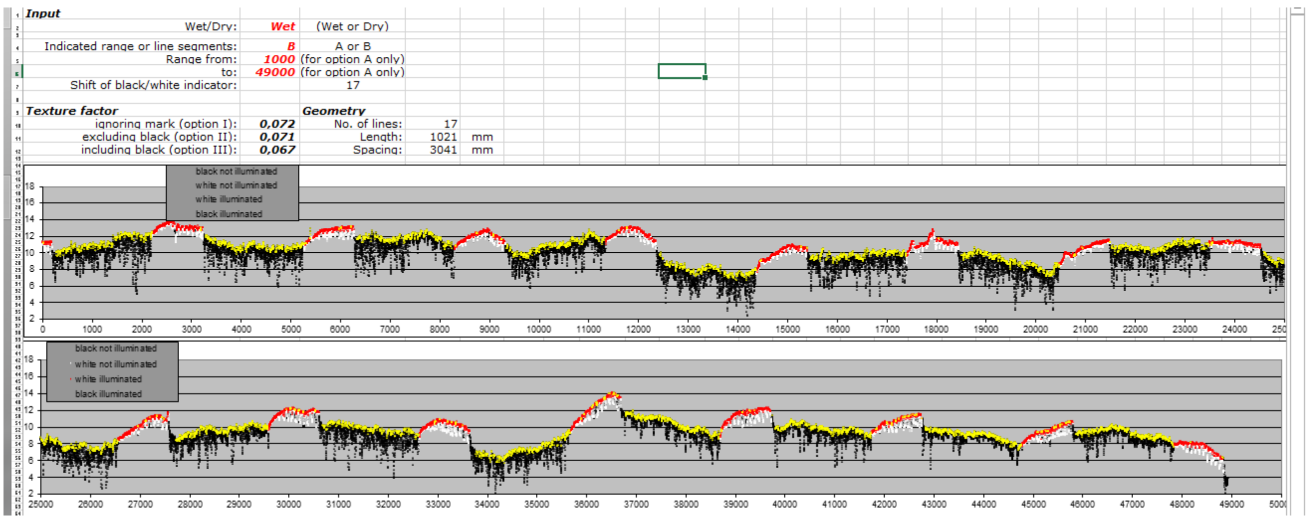

Figure B7. An example of the sheet for input and results.

Annex C

Detailed results of the field measurements

No.	*type*	*R_L(wet)*	*R_L(dry)*	*T*	*MPD*	*β*
1	Grooved	4.5	149	0.031	0.36	-
2	Grooved	38.0	153	0.060	0.52	-
3	Comb/stairflex	8.0	72	0.023	1.09	-
4	Comb/stairflex	19.0	116	0.071	0.97	-
5	Comb/stairflex	4.5	83	0.056	1.06	-
6	Comb/stairflex	12.0	128	0.100	1.01	-
7	Longflex	12.0	100	0.128	1.31	-
8	Longflex	6.0	26	0.037	1.28	-
9	Longflex	9.0	146	0.061	1.37	-
10	Longflex	19.0	176	0.112	1.86	-
11	Longflex	6.0	32	0.036	0.84	-
12	Longflex	10.0	98	0.030	-	-
13	Combflex	8.0	84	0.072	1.16	-
14	Combflex	8.0	47	0.038	1.23	-
15	Combflex	19.0	163	0.165	1.10	-
16	Combflex	8.0	47	0.054	0.79	-
17	Combflex	7.0	128	0.040	0.97	-
18	Stairflex	18.0	120	0.076	1.26	-
19	Stairflex	14.0	161	0.078	1.37	-
20	Stairflex	18.0	173	0.156	1.54	-
21	Stairflex	4.0	80	0.041	0.86	-
22	Stairflex	12.0	129	0.040	0.97	-
23	Dropflex	39.1	209	0.284	1.86	-
24	Chess pattern	28.8	203	0.243	1.33	-
25	Stairflex	26.9	194	0.280	1.47	-
26	Longflex	28.5	187	0.298	1.59	-
27	Grooved	12.7	112	0.055	0.56	-
28	Grooved	12.8	135	0.077	0.72	-
29	Starirflex	11.5	134	0.144	1.00	-
30	Stairflex	22.3	123	0.143	1.45	-
32	Grooved	18.8	208	0.068	0.68	-
33	Grooved	40.3	267	0.072	1.20	-
34	Grooved	39.3	170	0.104	1.00	-
35	Longflex	27.9	150	0.083	1.03	-
36	Grooved	22.7	222	0.067	0.42	-
37	Dropflex	21.4	206	0.046	0.52	-
38	Grooved	31.7	208	0.145	1.10	-
39	Stairflex	32.1	242	0.160	1.07	0.47
40	Grooved	9.1	267	0.082	0.65	0.51
41	Grooved	4.4	199	0.024	0.31	0.53
42	Stairflex	12.6	188	0.111	0.79	0.57
43	Grooved	4.1	194	0.080	0.76	0.46
44	Stairflex	33.2	233	0.261	1.09	0.48
45	Dropflex	27.1	151	0.123	0.69	0.52
46	Grooved	7.5	230	0.050	0.44	0.44
47	Grooved	13.3	186	0.104	0.91	0.50
48	Longflex	1.0	96	0.053	0.88	0.49
49	Dropflex	7.4	208	0.037	0.43	0.48
50	Grooved	6.8	213	0.059	0.57	0.53
51	Grooved	5.3	194	0.047	0.44	0.60
52	Grooved	15.1	218	0.092	0.84	0.49
54	Longflex	31.1	194	0.142	0.92	-
55	Longflex	12.6	92	0.160	1.05	-
56	Longflex	14.5	90	0.234	1.08	-
57	Dropflex	53.4	272	0.204	1.77	-
58	Longflex	6.8	91	0.133	0.88	-

Objects No. 31 and 53 are missing. No. 31 is a paint applied in a milled rumble strip and No. 53 is a flat road marking. Consequently, these are not considered being ordinary profiled road markings.

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