Draft report of the first round robin test for mobile reflectometers

Research carried out in the frame of the activities of CEN/TC226/WG2

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1   Introduction and aim of the study

Since the late 90's mobile reflectometers have been commercially available and used for check of the retroreflection of road markings. Earlier, road marking performance was checked using hand-held instruments, but increasing traffic was one reason for development of mobile instruments. The requirements on hand-held measurements and instruments are regulated in EN-1436, Annex B. This Annex also mentions mobile (vehicle mounted) instruments:

Vehicle mounted instruments are used to measure R_L values of road markings while moving at traffic speed, and can be used for longer stretches of road than portable instruments and in cases where the use of portable instruments requires extensive precautions, in particular on motorways.

Vehicle mounted instruments should in principle comply with the same requirements as for portable instruments, and should be able to cope with the movements of the vehicle and with changing conditions of daylight. However, the operation at speed may cause additional difficulties of the measurement, which may lead to compromises with requirements or cause additional variation of measured values.

Portable and vehicle mounted instruments are to be calibrated, maintained and used according to instructions by the instrument supplier.

When those paragraphs were written the experience of mobile reflectometers was small. That is the reason why it was written in rather vague terms like "operation at speed ….may lead to compromises with requirements or cause additional variation of measured values".

Since EN-1436 was revised in 2006, the use of mobile instruments has increased and several instruments are now commercially available. However, experience from older instruments has shown that the speculations above were correct: measurement errors are larger for the mobile than for the hand-held instruments.

During its meeting on 18 and 19 April 2010 in Istanbul, CEN/TC226/WG2 asked the Expert Panel to investigate this aspect further by means of the organization of a round robin test. The aim of this study was to quantify those measurement errors, i.e. to estimate the accuracy, precision, uncertainty and repeatability of the mobile instruments commercially available today (September 2010). The aim was to increase knowledge, not only of measurement errors, but also of the operation of mobile instruments, and to use this new information in a standard.

In order to get more experience of mobile instruments, the Expert Panel of WG2 arranged demonstration and validation measurements in Belgium between September 13th and September 15th 2010. The measurement programme was set up by BRRC (Luc Goubert) with assistance of VTI (S-O Lundkvist).

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2 Method

Users and manufacturers of mobile reflectometers in Europe were invited to participate in the evaluation and demonstration of different types of mobile instruments. Positive response came from two users and two manufacturers according to Table 1 (in alphabetical order):

Table 1   Participants in the test measurements in Belgium in September 2010.

Company	Country	Instrument	User/manuf.
DELTA Light and Optics	Denmark	LTL-M	manufacturer
Ennis Prismo	UK	Ecodyn 30	user
Euroconsult NT	Spain	Ecodyn 30	user
Zehntner GmbH[1]	Switzerland	Zehntner ZDR 6020	manufacturer

The users and manufacturers participated on their own expense. Each participant was responsible for the calibration of the instrument and for delivery of the data. The three types of mobile instruments, LTL-M, Ecodyn 30 and Zehntner ZDR 6020, are described in detail in Annex A, B and C, respectively. A commitment to the participants was that the instrument could not be identified in the chapters describing the results and conclusions. Therefore, the instruments were by random assigned a number between 1 and 4.

In advance, 23 test sites were defined. However, two of the sites were excluded: one because of road work and one because the hand-held measurements were impossible to carry out due to the amount of traffic. Thus, measurement on 21 test sites remained – 19 continuous plane and profiled edge lines and two broken (3 m line, 9 m gap) lane lines, each of the length 200 metres. The locations of the test sections and pictures of the concerned markings can be found in Annex E.

In order to estimate the repeatability of the mobile instruments, more than one measurement round was carried out at eight of the sites. The remaining twelve test sites were only measured once. The mobile measurements were carried out in approximately 50 km/h and at every site all mobile readings were taken within a couple of minutes. Figure 1 shows the mobile instruments, measuring test site number 1.

Figure 1   The four mobile instruments measuring test site number 1.

As reference readings of a hand-held instrument of type LTL-2000 of manufacturer DELTA were used. This instrument was checked and calibrated both before and after the measurement series to make sure that there was no bias in the reference data. Readings with the hand-held instrument were taken approximately every sixth metre. This meant 32 – 38 readings at each test site, except at four sites with very heavy traffic, where only 18 readings, distributed evenly over the stretch, were taken. It should be noted that, although the hand held instrument was properly serviced, calibrated and operated, there is also an uncertainty on its results, due to the sampling on the one hand and the usual instrument uncertainty (not exceeding 5 % RMS deviation according to the manufacturer) on the other hand. To consider the results of the hand held instrument as the "true" values is hence only an approximation of the reality.

All measurements were carried out between the 13th and 15th of September 2010 on dry road marking surfaces in partly cloudy weather conditions. The time between the hand-held and mobile measurements was short – less than one hour.

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3 Analysis

3.1 Output from the instruments

In this study, four different instruments of three types have been tested against readings from a hand-held instrument. It is important to stress that the reading from each type of instrument does not represent the retroreflection of exactly the same area:

The **hand-held** readings with the LTL-2000 were taken in the middle (transverse) of the road marking. This means that the operators made a judgement of where the middle was. This may be difficult on a wide road marking (some were of the width 0.30 metres) which means that on this type of marking the measurement point may be misaimed a couple of centimetres or so. The measurement area of the hand-held instrument is approximately 0.04×0.4 metres and on most test sites approximately 35 readings were taken. Sampling means that there is an uncertainty in the average R_L-value which is dependent on the sample size and the variance of the retroreflection, both along and transverse the road marking.

The measured area of the **mobile instrument 1** coincides with the road marking area, both longitudinally and transversally. Consequently, the readings of this instrument are comparable to the hand-held readings only if the road marking retroreflection is homogenous.

The measurement results of the **mobile instrument 2** can be analysed after the measurements have been completed and readings can be obtained from the whole, or any part of the road marking. This means that, when comparing with the hand-held measurements, the measurement area should be located in the centre of the road line and when comparing with instrument 1, the entire area should be used. Therefore, the delivery of mobile instrument 2 was readings representing 0.05 metres in the middle (transverse) of the road marking, and, also readings representing the entire road marking area.

Mobile instrument 3 uses 14 photocells to measure the road marking retroreflection. The output is an average of the two photocells which show the highest value. As each photocell covers approximately 0.04 metres, the reading represents a value of width 0.08 metres. If the road marking retroreflection is homogenous, the output from this instrument should be comparable with the output of the other instruments. However, if the retroreflection varies widely transverse to the road marking, in most cases instrument 3 should read a higher value than the hand-held instrument. Only if the maximum is in the middle of the line, readings from instrument 3 would be comparable to readings of the hand-held and the mobile instrument 2.

Mobile instrument 4 is of the same make as instrument 3, and, therefore the output should be comparable to readings from that instrument.

Figure 2 shows the difference in retroreflection dependent on if the entire area or 0.05 metres in the middle of the road marking is taken into consideration.

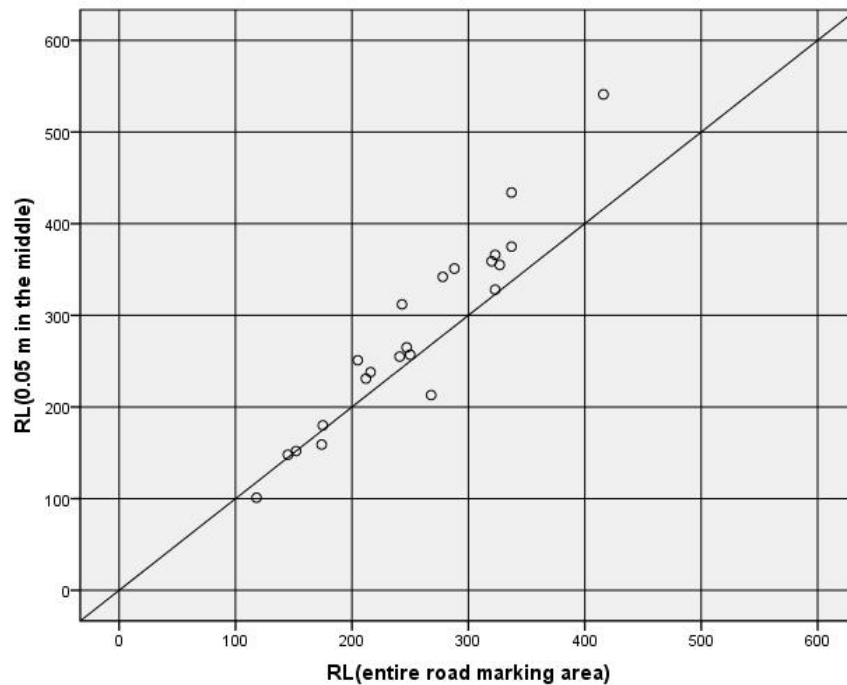L. Goubert (BRRC) – S.-O. Lundkvist (VTI)

Figure 2   Comparison of the retroreflection of 22 road markings when the output represents the entire area or 0.05 metres in the middle of the marking.

Figure 2 shows a deviation of in average about 11 %. Obviously, the majority (18 out of 22) of the road markings has the highest value in the middle (transverse) of the surface as the readings are lower when the output derives from the entire surface. However, in all calculations below, accuracy, precision and uncertainty is calculated using the hand-held readings as reference. In other words, LTL-2000 is considered to measure the "true" retroreflection.

The delivery from the mobile instruments was an average value of the entire 200 metres long test site, but also of this site divided into stretches of 50 metres. This latter output has not been used, as it is difficult to divide the output from the hand-held files into stretches of exactly 50 metres. Consequently, such an analysis would not contribute to the conclusions of the measurements. However, one test site, number 9, was partly located in a tunnel (50 metres in the beginning of the stretch), where the road marking was extremely dirty. This part of that test site has been excluded and, therefore, the length of test site number 9 is 150 metres.

The analysis of the readings of one of the mobile instruments shows that the retroreflection of the road markings at one test site, number 17, has a very large variation in the transverse direction of the road line. This fact is illustrated in Figure 3, where a narrow light band to the right of the centre of the surface, can be seen. This band is located just a couple of centimetres from the centre of the road marking and shows a retroreflection of more than 210 mcd/m^2/lx, while the R_L-value in the centre is approximately 150 mcd/m^2/lx.

One can realize that, regarding this test site, the discrepancy between the readings of the instruments may be great as the retroreflection shows a large transverse variation close to the middle of the road marking. Generally, it is no good idea to exclude data, but in this case it is obvious that including number 17 in the analysis may introduce large errors in the result.

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Just before the round-robin test instrument 1 had a small accident which unfortunately destroyed the instrument. This meant that this instrument was replaced by a devices used for development of filters. Therefore, by mistake, some filter settings of the software were set incorrectly. This fact has probably caused the large deviation between readings of the LTL-2000 and instrument 1 for centre lines.

Referring to what is stated above, a separate analysis where test sites 17, 1L and 4L have been excluded is shown in Annex D.
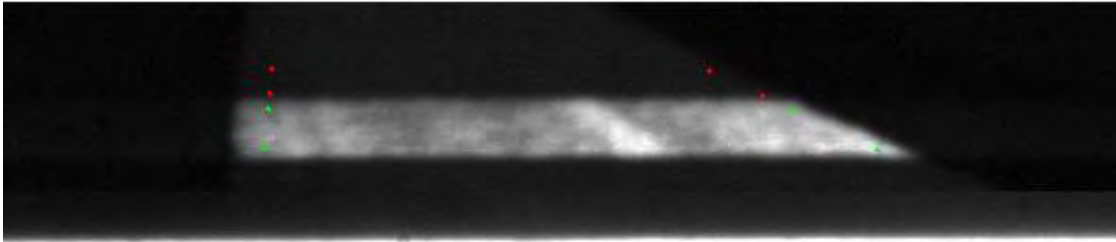

Figure 3   The appearance of the road marking at test site number 17. The bright band, meaning high retroreflection, is located towards the shoulder a few centimetres from the middle of the edge line.

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3.2 Statistical calculations

Below, the following denotations are used:

$R_L(X)$ The average R_L of the 21 test sites when using instrument X.
$R_L(LTL2000)$ The average R_L of the 21 test sites when using LTL-2000.
$R_{Lharm}(X)$ The average R_L of the 21 test sites when the individual readings of the
                                  mobile instrument X are *harmonized*[2] with $R_L(LTL2000)$.
$\Delta R_L(X)$ The average difference between $R_L(X)$ and $R_L(LTL2000)$.
$\left|\Delta R_{Lharm}(X)\right|$ The absolute value of the average difference between individual readings of
                                  $R_{Lharm}(X)$ and $R_L(LTL2000)$.
$\left|\Delta R_L(X)\right|$ The absolute value of the average difference between individual readings of
                                  $R_L(X)$ and $R_L(LTL2000)$.
ε_{acc} The accuracy (systematic error) of the measurements.
ε_{prec} The precision (random error) of the measurements.
ε_{unc} The uncertainty (total measurement error) of the measurements.
ε_{rep} The repeatability of the measurements.

For mobile instrument X the accuracy, $\varepsilon_{acc}(X)$, is calculated as

$$\varepsilon_{acc}(X) = \frac{\sum_{i=1}^{n}(R_{Li}(X) - R_{Li}(LTL2000))/R_{Li}(LTL2000)}{n} \quad (1)$$

where $R_{Li}(X)$ is the reading of instrument X at test site i, $R_{Li}(LTL2000)$ is the hand-held reading at test site i and n the number of test sites.

Furthermore

$$\varepsilon_{prec}(X) = \frac{\sum_{i=1}^{n}\left|R_{Liharm}(X) - R_{Li}(LTL2000)\right|/R_{Li}(LTL2000)}{n} \quad (2)$$

where $R_{Liharm}(X)$ is the harmonized retroreflection when using instrument X at test site i:

$$R_{Liharm}(X) = R_{Li}(X) - \Delta R_L(X) \quad (3)$$

Finally, the concept uncertainty, $\varepsilon_{unc}(X)$ is defined as

$$\varepsilon_{unc}(X) = \frac{\sum_{i=1}^{n}\left|R_{Li}(X) - R_{Li}(LTL2000)\right|/R_{Li}(LTL2000)}{n} \quad (4)$$

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[2] i.e. corrected for the systematic error

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At those test sites where more than one measurement round was carried out with the mobile instruments, the repeatability was calculated as

$$\varepsilon_{rep}(X) = \frac{\sum_{i=1}^{n} \left| R_{Lip}(X) - R_{Liq}(X) \right| / R_{Liq}(X)}{n} \quad (5)$$

where R_{Lip} and R_{Liq} refer to the retroreflection of measurement round p and q, respectively, at test site i using instrument X. Thus, ε_{rep}, refers to the repeatability of two measurement rounds. Some test sites were measured more than twice with each mobile instrument. In that case the repeatability was calculated as an average of all possible combinations.

When interpreting the measurement errors, it is important to bear in mind that the accuracy, precision, uncertainty and repeatability are related to the variance in data *between* the test sites. Besides, there is also a variance *within* each test site, which partly is a true variance in the retroreflection along the stretch, partly a measurement error. However, this within test site variance has not been analysed.

Furthermore, it can be stressed that linear error terms have been calculated. Error terms based on the standard deviation would have been larger and outliers would have had a larger influence on the estimated measurement errors. This is shown by the r^2-values in Figures 4 – 7.

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4 Results

4.1 Measured retroreflection

Table 2 shows the estimated average retroreflection for each of the 21 test sites.

Table 2   The retroreflection at 21 test sites of 200 metres. Average of 1 – 6 measurement rounds at a stretch of approximately 200 metres.

Test site	LTL-2000	Mobile instrument 1	Mobile instrument 2	Mobile instrument 3	Mobile instrument 4
1	110	120	101	223	157
2	260	254	257	367	293
3	279	251	265	362	254
4	260	363	213	464	327
6	353	314	355	362	348
7	247	229	231	319	239
8	263	238	255	342	254
9	178	172	154	278	183
10	242	210	251	371	293
11	365	286	359	451	359
12	383	292	375	374	383
13	215	230	238	411	321
14	359	325	342	487	390
15	338	341	351	374	406
16	307	303	312	194	325
17	231	207	159	141	239
18	359	345	328	475	399
19	489	512	434	385	477
20	507	539	541	444	581
1L	150	62	148	144	161
4L	419	176	366	405	362

Test sites 1L and 4L are broken lane lines, while the rest are continuous edge lines.

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4.2 Accuracy (systematic errors)

Table 3 shows the accuracy of the four mobile instruments calculated according to Eqn. (1).

Table 3   The accuracy estimated from field measurements at 21 test sites. Four mobile instruments compared to the hand-held measurements using the LTL-2000.

Instrument	R_L	ΔR_L	ε_{acc}
LTL-2000	301	-	-
Mob. Instr. 1	275	- 26	- 8.4 %
Mob. Instr. 2	287	- 13	- 4.8 %
Mob. Instr. 3	351	+ 50	+ 23.7 %
Mob. Instr. 4	321	+ 21	+ 9.1 %

As stated before, the measurement area of the four types of instrument is not equal. Therefore, instruments 3 and 4 should read a higher value than the LTL-2000 and instrument 2 a value equal to the hand-held instrument. The output from instrument 1 represents the entire road marking area and can, therefore, be higher or lower than the hand-held reading, dependent of the distribution of R_L across the line. All these assumptions are in good agreement with the results, even if it is impossible to estimate if the size of the differences is correct.

4.3 Precision (random errors)

To find the precision of the instruments, the R_L-values in Table 3 are harmonized according to Eqn. (3). This harmonization enables an analysis of the precision, independent of the accuracy. Table 4 shows the random errors when the systematic deviation has been rejected, which estimates the precision of the measurement.

Table 4   The precision estimated from field measurements at 21 test sites. Four mobile instruments compared to hand-held measurements using the LTL-2000.

Instrument	R_{Lharm}	$\left|\Delta R_{Lharm}\right|$	ε_{prec}
LTL-2000	301	-	-
Mob. Instr. 1	301	44	14.8 %
Mob. Instr. 2	301	21	7.1 %
Mob. Instr. 3	301	72	26.9 %
Mob. Instr. 4	301	30	10.8 %

Particularly, the precision of instrument 3 is poor. It is worth to note that instruments 3 and 4 are of the same type and they should therefore have about the same performance. It is difficult to explain the large difference in precision between these two instruments, but earlier experience tells that the figure for instrument 3 is too high.

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4.4   Uncertainty

The concept "uncertainty" is the overall concept which involves both accuracy and precision according to Eqn. (4). Table 5 shows the uncertainty of the four mobile instruments.

Table 5   The uncertainty estimated from field measurements at 21 test sites. Four mobile instruments compared to the hand-held measurements using the LTL-2000.

Instrument	R_L	$|\Delta R_L|$	ε_{unc}
LTL-2000	301	-	-
Mob. Instr. 1	275	44	14.8 %
Mob. Instr. 2	287	22	7.4 %
Mob. Instr. 3	351	88	35.0 %
Mob. Instr. 4	321	32	12.4 %

Some of the uncertainty for instrument 1, 3 and 4 may be explained by the difference in measurement area as discussed in Chapter 3. However, the uncertainty of instrument 3 is extremely large, which probably is due to some malfunction or operational mistake

4.5   Repeatability

Table 6 shows the repeatability of the four mobile instruments.

Table 6   The repeatability of the four mobile instruments. Average of 1 – 5 repetitions at eight test sites (Mob. Instr. 1 only 2).

Instrument	ε_{rep}
Mob. Instr. 1	1.8 %
Mob. Instr. 2	1.8 %
Mob. Instr. 3	2.9 %
Mob. Instr. 4	3.3 %

The figures in Table 6 show good repeatability of all four instruments.

5   Correlation to the hand-held measurements

Figures 4 to 7 show the regression between on one hand the hand-held and on the other hand the mobile measurements based on 21 test sites. In each figure the r^2-value is given. This value can be interpreted as the percentage of the total variance in data that is explained by a true variance in road marking retroreflection. The rest are measurement errors. The square root of r^2 is the correlation coefficient.

Figure 4 shows the regression line between readings from **the mobile instrument 1** and the LTL-2000.
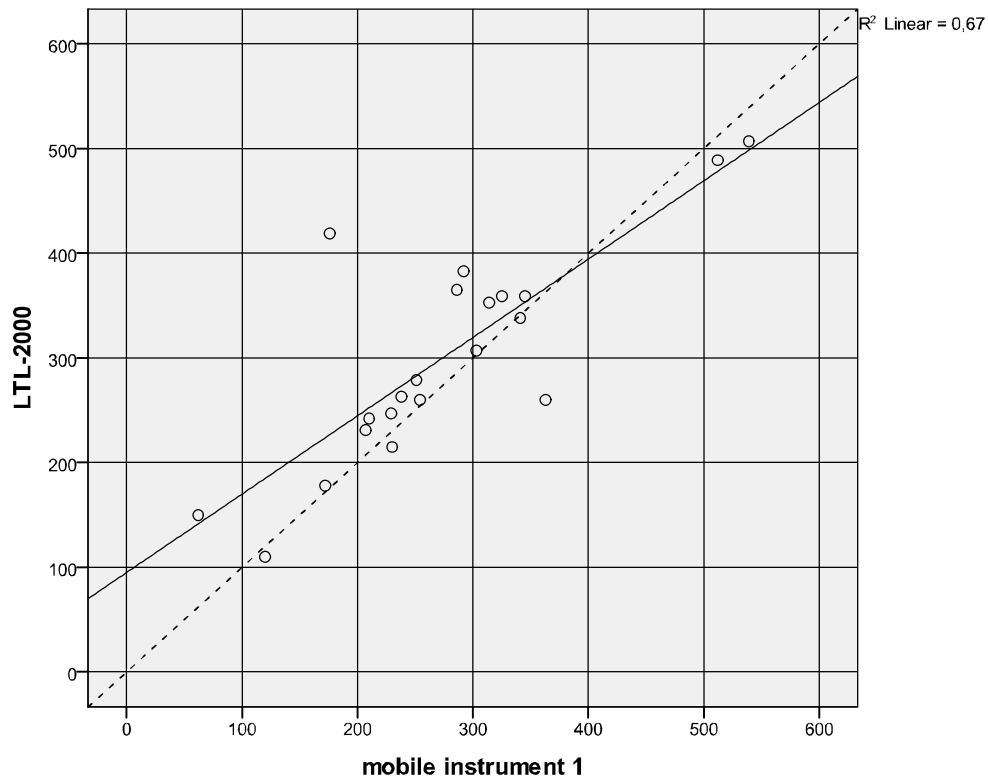
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*Figure 4   The regression line for mobile instrument 1 and LTL-2000 shown as the solid line.
The dashed line is x = y.*

As can be seen in Figure 4 there are some outliers; among them are the two lane lines. r^2 shows that 64 % of the total variance in data is explained by the variation in road marking retroreflection. The rest of the variance, 36 %, is due to the random errors in measurements.

Figure 5 shows the regression line between readings from **the mobile instrument 2** and the LTL-2000.
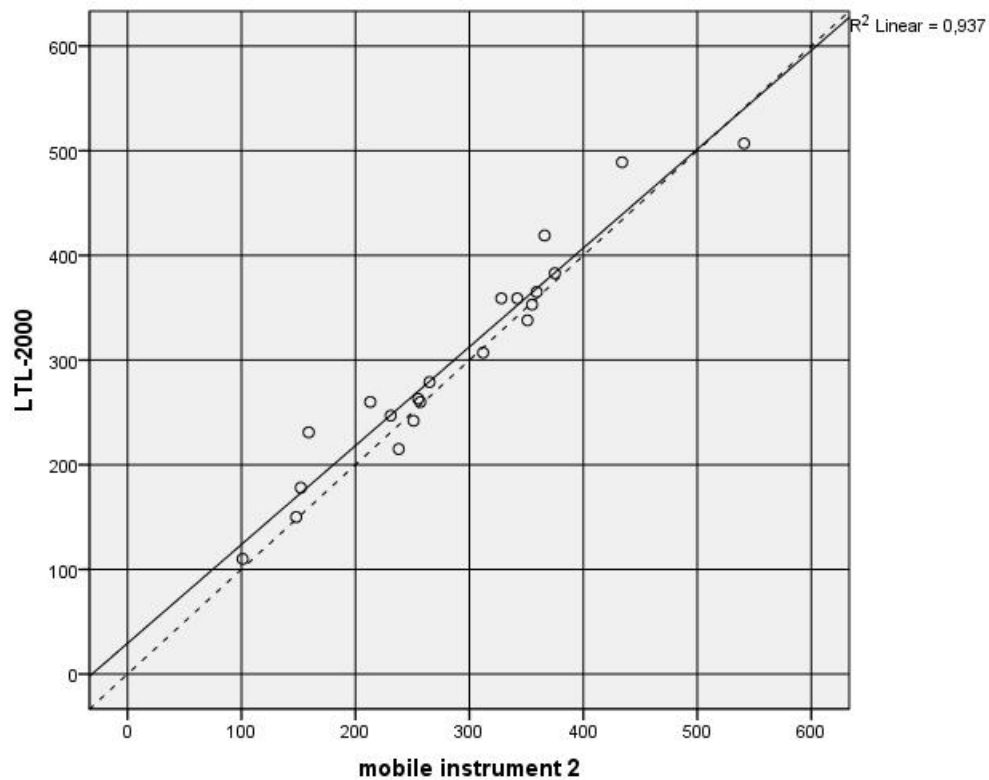
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Figure 5   *The regression line for mobile instrument 2 and LTL-2000 shown as the solid line.*
                  The dashed line is x = y.

Figure 5 shows that the regression line of intrument 2 is very close to $x = y$. r^2 indicates that
6 % of the total variance in data arises from measurement errors; the rest, 94 %, is the true
variance of the road marking retroreflection among the 20 test sites.

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Figure 6 shows the regression line between readings from **the mobile instrument 3** and the LTL-2000.
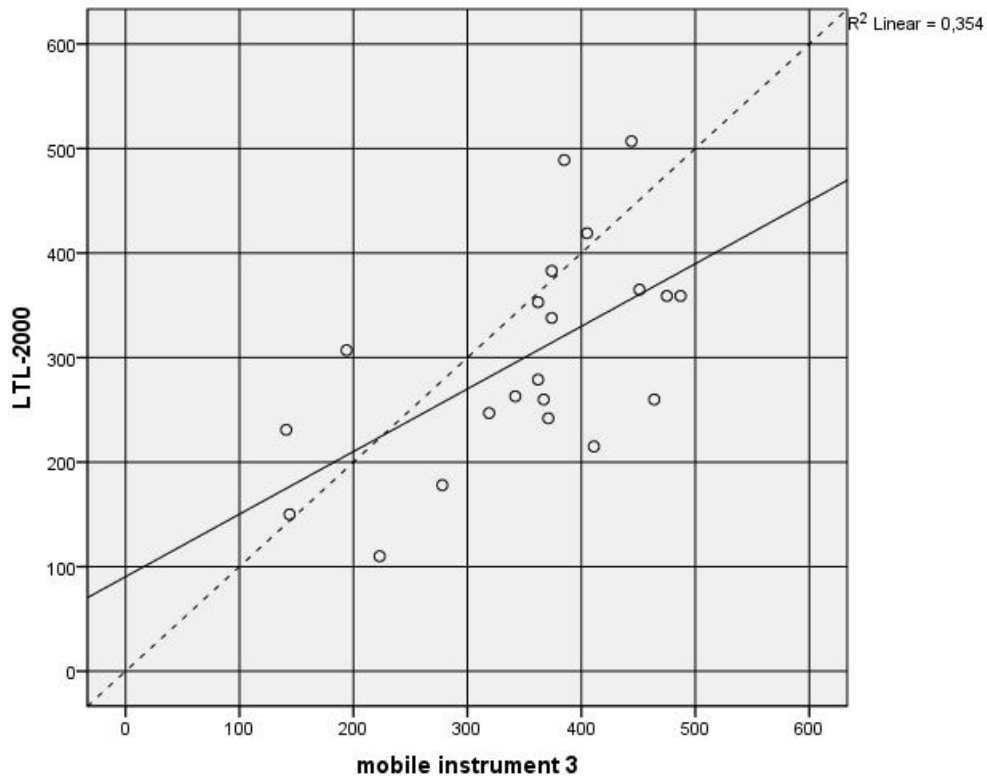

Figure 6   *The regression line for mobile instrument 3 and LTL-2000 shown as the solid line. The dashed line is x = y.*

Figure 6 shows that both systematic and random errors are large for instrument 3. In fact most of the variance in data arises from the measurement errors – only 35 % from the variance in road marking retroreflection.

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Figure 7 shows the regression line between readings from **the mobile instrument 4** and the LTL-2000.
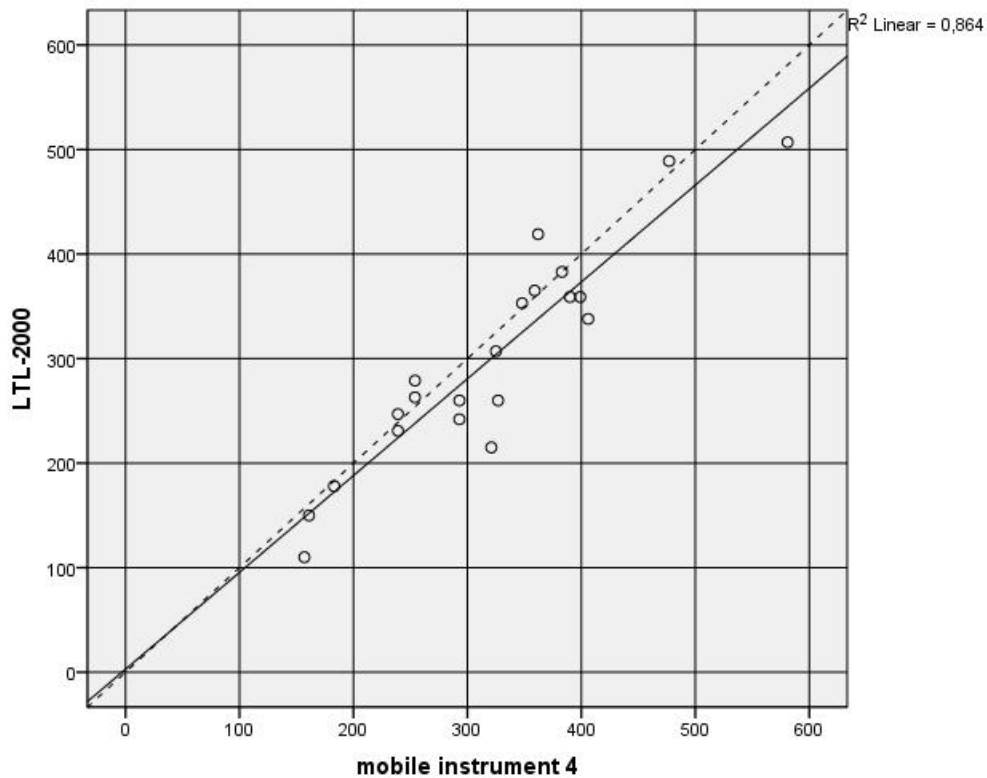

Figure 7   *The regression line for mobile instrument 4 and LTL-2000 shown as the solid line. The dashed line is x = y.*

Figure 7 shows a high correlation between readings of the two instruments. The systematic discrepancy of approximately 10 % (see Table 3) can probably to some extent be explained by the difference in measurement areas.

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6 Use of the results

It is for the Expert Panel of CEN/TC 226 WG2 to evaluate the uncertainties derived in this study and to arrive at recommendations for mobile measurement in view of the methods used by the instruments that took part and as described in annexes.

At this point it is recommended that mobile instruments are designed to be easy to handle and robust in use, so that the errors as observed in the study are avoided.

Further, it is recommended that a single method of dealing with the width of road markings is chosen in view of the transverse non-uniformity observed in this study.

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Annex A

Description of the LTL-M

A1   Introduction to the LTL-M

The LTL-M measures the coefficient of retroreflected luminance R_L while driving at speed. The measuring geometry is the 30 m geometry of EN 1436 in a scale of 1:5 meaning for instance that the nominal measuring distance D_0 is 6 m. The locations of the detector and the light source are interchanged.

The light source is a xenon flash lamp that emits flashes with duration of typically 10 to 20 microseconds. By means of suitable optics the flash lamp illuminates a field on the road that is approximately 1 m long and 1 m wide.

The detector is a digital camera used with a fixed exposure time set typically to 10 to 20 microseconds.

The flashes of the flash lamp and the exposures of the camera are synchronized. The current rate is 25 flashes and exposures per second. The software analyses mentioned in the following are carried out in real time.

A field of the road is shown in a part of the image that has a width of more than 1000 pixels and a height of typically 100 pixels. This field is a bit wider than the illuminated field but much longer, covering a distance range from approximately 4 to 8 m.

Suitable software analyses this part of the image and determines if it contains a longitudinal road marking. If so, the software determines the sides enclosing the road marking surface and also possible fronts and ends of road markings in broken lines. The software also identifies those parts of the road marking surface that are illuminated by the flash lamp. Additionally, the software determines the actual distances D to locations on the surface that correspond to each of the pixels.

Figure A1 shows a typical image with a 30 cm edge line.

By means of suitable optics another part of the image is made to show the light source itself in such a way that it represents the distribution of the illuminance E_0 on a vertical surface at the distance D_0. The software uses this distribution to determine the illuminance E created by the flash lamp at locations on the road marking surface by $E = E_0 \times (D_0/D)^2$. The term $(D_0/D)^2$ represents the distance law of illumination.

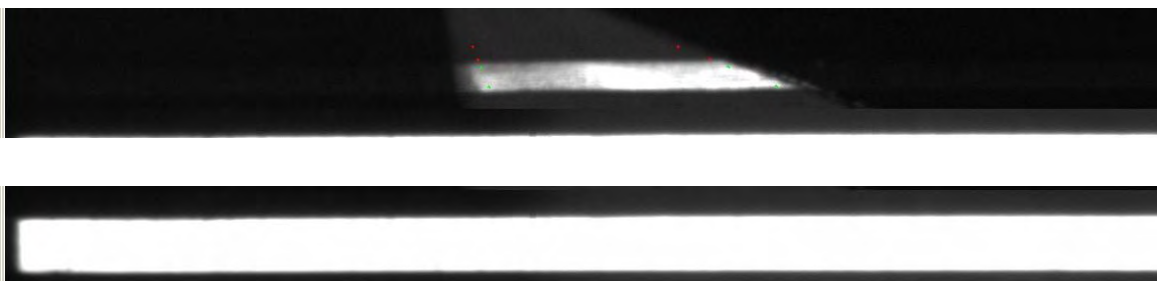Figure A1 contains also a typical image of the light source.

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On this basis, the R_L value at a location is derived by:

$$R_L = C_0 \times C \times (P-D)/E$$

where $\quad$ C_0 is a correction factor

$\quad$ C is a calibration factor

$\quad$ P is the value of the pixel corresponding to the location

and $\quad$ D is a residual level of daylight.

The result is expressed as the average R_L value for a field on the illuminated part of the road marking surface.

Two such fields are indicated in figure A2. The upper field corresponds to a 5 cm wide lane in the middle of the marking surface, while the lower field includes almost all the width of the road marking.
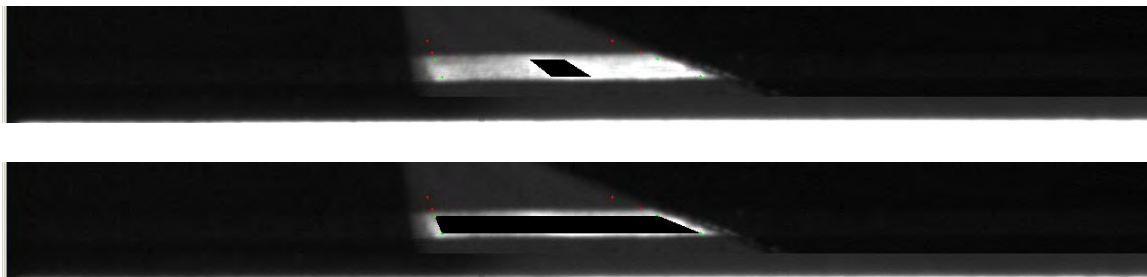

Figure A2   Two fields for integrating the R_L value.

NOTE: The images are actually wider than shown in figures A1 and A2.

The retroreflected luminance of the road marking surface dominates over daylight during the brief period of the flash. However, in bright daylight there is a residual level of daylight which is determined for a field on a part of the road marking surface that is not illuminated by the flash lamp.

The residual level of daylight that is used in the current image is actually one that has been determined from a previous image, while the level determined from the current image is saved for use with a later image. In this way, the residual level of daylight is determined at the correct location and just a short time before it is used, typically 1/25 of a second earlier.

Linearity and uniformity of the response of the camera pixels is ensured on the basis of an initial procedure carried out in laboratory conditions.

The LTL-M by its construction and way of working ensures an almost constant sensitivity over the width of the illuminated field. However, a global calibration is carried out at intervals

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in order to eliminate possible small variations. To this purpose, the LTL-M is aimed to illuminate a uniform white surface placed at the distance D_0 and additional software is initiated. The software determines and stores an array of the above-mentioned correction factors C_0 as an average of 100 exposures and stores the values. The software also derives some geometrical measures that are used for the above-mentioned analyses of road images during driving.

The value of the above-mentioned calibration factor C is derived in a calibration procedure using a calibration standard of one of the types used for the handheld retroreflectometers LTL 2000, LTL-X or LTL-XL. Other calibration standards may be used as well. The calibration standard is placed at the distance D_0, the LTL-M is aimed to illuminate the ceramic front surface of the standard and additional software is initiated. This software determines C as an average for 100 exposures and stores the value.

The software used during driving determines not only the R_L value as described in the above, but also:
- the geometry of the road marking including the width and gaps in broken lines
- the geometry of measurement including the height position of the equipment, the measuring distance and three angles relating to the orientation of the equipment relative to the road marking surface.

The software derives all the above-mentioned values for one or two lines (for instance double centre lines) simultaneously.

A2   Compliance with EN 1436

The LTL-M works in accordance with EN 1436 by:
- having a spectral correction that allows measurement of both white and yellow road markings
- complying with the standard measuring condition in terms of angles, apertures and measured field
- having sufficient linearity and range
- providing R_L values that are unaffected by ambient daylight
- providing R_L values that are robust to tilts and lifts
- using a calibration standard with a traceable R_L value that can also be independently calibrated.

Tilts and lifts are unavoidable in practical driving conditions being caused by movements of the vehicle, camber of the road or other factors. Compensation for the effects of the distance law of illumination is obtained in the way explained in A1. Additionally, effects of a geometrical factor that is inherent in the R_L value are avoided by excluding the geometrical factor in the measured value. This is obtained by the interchange of the detector and the light source.

NOTE 1: This kind of robustness is provided also by the handheld retroreflectometers LTL 2000, LTL-X and LTL-XL. In these handheld retroreflectometers, robustness to distance is provided by the use of collimating optics that create a virtually infinity measuring distance. The exclusion of the geometrical factor from the measured value is obtained by an arrangement of the fields of illumination and measurement, so that the illuminated field is enclosed within the measured field.

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NOTE 2: The geometrical factor is the ratio $\sin\varepsilon/\sin\alpha$, where ε and α are the illumination and observation angles. The correct value for the 30 m geometry is 0,542 which is applied as a factor.

A3   Other comments

The various features of the LTL-M (robustness to tilts and lifts, feedback from the light source, precise identification of the relevant field and precise compensation for any residual daylight) brings validity to not only average R_L values for 50 or 100 m site, but also to the individual measured R_L values at locations.
The value of calibration factor C is stable over time because of the feedback from the flash lamp. However, it is easy to do calibrations on location.

The width of the field of more than 1 m, refer to D.1, allows for comfortable steering of the vehicle.

The information on the geometry of measurement, refer to D.1, ensures that the alignment can be kept within tolerances.

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Annex B

Description of the Ecodyn 30

Ecodyn

**A device for continuous single-pass day-time surveys
of the night- and day-time visibility of road markings**

Ecodyn continuously measures the coefficients of retroreflected luminance of
road markings as well as their day- and night-time contrasts with the pavement.
This helps the road manager to schedule campaigns for the replacement of road
markings, to check the quality of laying of marking products, and to monitor
their development with time. In this way a substantial contribution can be made
to improving road safety.

Principle

The coefficient of retroreflected luminance of road markings characterizes their capability of
backscattering light from vehicle headlamps to the driver. It is denoted as RL and expressed
in mcd/m³.lx. To measure it, Ecodyn emits a frequency-modulated white light and receives
the retroreflected luminous flow, superimposed by the flow from ambient illumination.
Appropriate signal processing makes it possible to separate the two types of light and to
calculate the RL coefficients as well as the day- and night-time contrasts of the marking with
the pavement.

The measuring geometry complies with the prevailing European standard NF EN 1436, i.e.,
an angle of 1.24° with the plane of the pavement surface for transmission and an angle of

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2.29° for reception. It simulates the visibility of a road marking to a vehicle driver viewing it at a distance of 30 m.

Description

Ecodyn is installed on a specially equipped one-box vehicle. It comprises a measuring box carried outside the vehicle, an electronic box for sending out and receiving signals, and a microcomputer for data acquisition and processing.

Data acquisition (readings ≈ every 40 cm) does not depend on the speed of the vehicle. The position of the device with respect to the road marking is monitored by the driver using a bargraph situated on the dashboard in the vehicle.
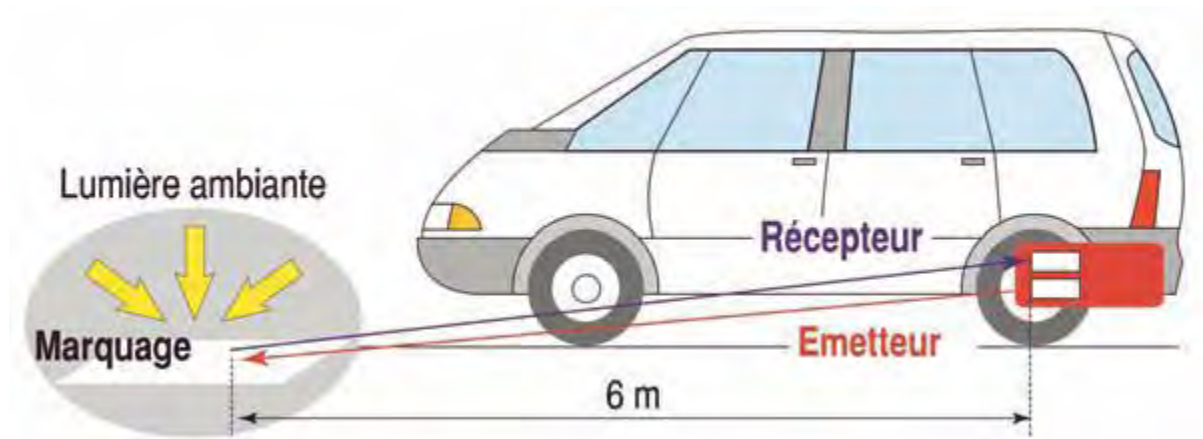
Principle drawing
(Lumière ambiante = Ambient light; Marquage = Marking; Récepteur = Receiver; Emetteur = Transmitter)

Characteristics

Metrological characteristics

- Transmission ("entrance") angle: 1.24°.
- Reception ("observation") angle: 2.29°.
- Average illumination distance: 6 m.
- Width of illuminated area = 0.5 m.
- Length of observed area = 1 m; width of observed area = 0.5 m.

Mechanical and electrical characteristics

- Host vehicle: climate-controlled one-box vehicle (with a rigid suspension).
- Measuring box: length = 0.75 m, width = 0.21 m, height = 0.42 m.
- General power supply by the 12-V battery of the vehicle.
- Light source: 75-W halogen lamp with a life of 3,000 h.
- Detection of luminous flow received by linear photodiode matrix.
- Reception on 14 tracks.

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Visualization of a marking strip
(Mesure détaillée sur la distance = Measured values versus distance;
Voir toute l'exploitation … = See the full range of data …)
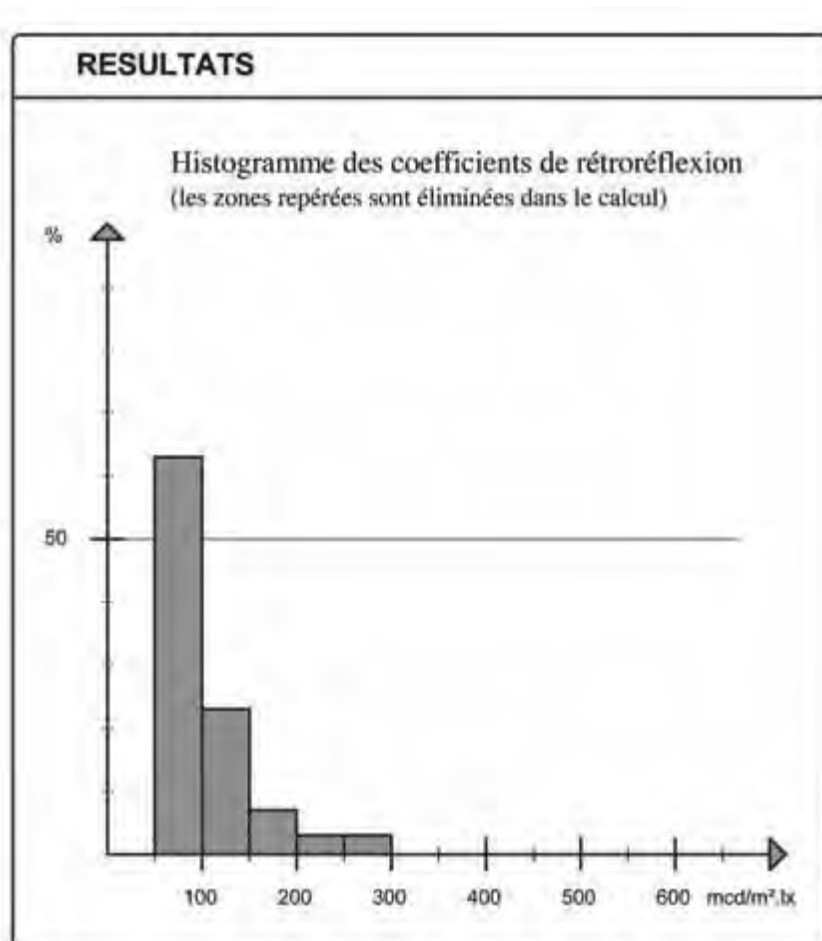
(RESULTATS = RESULTS; Histogramme … = Histogram of retroreflection coefficients (area locations are disregarded in the calculation)

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Conditions of operation and limitations to use

- Clean and dry marking, no traces of salt.
- Weather conditions: dry weather, t° > 5 °C.
- Speed: 0 to 110 km/h.
- Integrated with the traffic stream, no special protection – except on 2 x 2-lane roads (measurements on left edge lines).

Applications

- Continuous measurement of the night- and day-time visibility of road markings (readings ≈ every 40 cm).
- Representation of results as values averaged over zones with a length do be defined by the operator (100 m, 500 m …).
- The measuring range extends from a few mcd/m².lx to about 2,000 mcd/m².lx.

Expression of results

In addition to visual displays in the form of lists and graphs, the results can be incorporated in a data bank and presented in the form of route or map diagrams.

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Annex C

Description of the Zehntner ZDR 6020

The ZDR 6020 measures the night visibility of road markings (R_L) under day light conditions. The measuring geometry is fully in accordance with EN1436 and ASTM 1710. Every popular road marking system can be measured. Moreover the ZDR 6020 system is also approved by StrausZert, an accredited test institute. The device is also calibrated to a traceable standard.

The measuring area is illuminated by a stabilized halogen lamp which projects a field on the road that is 6m in front of the measuring head.

The detector consists of 16 V(λ) adapted sensors which measure the retroreflected light over a measuring area which is 500mm wide and 1000mm long. Because the illuminated area is larger than the measuring area the system is largely immune against tilts and lifts caused by the vehicle. The day- and stray light gets eliminated by a system which is derived from the lock-in principle. All sensors are aligned by an initial procedure in our laboratory for perfect linearity.

During periodic intervals a dynamic calibration is carried out. A dynamic calibration gives the advantage that the ZDR 6020 measuring system gets calibrated under measuring conditions. In dynamic measuring mode the system gets calibrated to a calibration standard which was measured with a handheld device before. However if there is no possibility for a dynamic calibration also a static calibration can be done while standing.

In measure mode 600 single measurements per second will be done. This high speed data acquisition gives the possibility to measure also under fast changing light conditions such as alleys. Digital signal processors analyze the signal from every sensor in real time. Software computes the width of the measured marking to adapt software filters for calculating an average R_L value from the whole width of the road marking. Additionally the software detects also gaps and raised reflective pavement markings (RRPM's) for computing a R_L value only from the road marking. Furthermore a self diagnostic algorithm assures that the system is always in good condition.

Fast data acquisition in combination with a large measuring field gives the advantage that the measuring vehicle can drive up to 120km/h.

According to the customer needs the interval where an R_L average gets stored can be adapted manually in the software, typically is an interval of 50m but it can also continuously be set down to 10m.

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Annex D

Results with test site number 17, 1L and 4L excluded

Tables D2 – D6 show the tables corresponding to Tables 2 – 6, but when test sites number 17, 1L and 4L have been excluded.

Table D2   The retroreflection at 18 test sites of 200 metres. Average of 1 – 6 measurement rounds at stretches of approximately 200 metres.

Test site	LTL-2000	Mobile instrument 1	Mobile instrument 2	Mobile instrument 3	Mobile instrument 4
1	110	120	101	223	157
2	260	254	257	367	293
3	279	251	265	362	254
4	260	363	213	464	327
6	353	314	355	362	348
7	247	229	231	319	239
8	263	238	255	342	254
9	178	172	154	278	183
10	242	210	251	371	293
11	365	286	359	451	359
12	383	292	375	374	383
13	215	230	238	411	321
14	359	325	342	487	390
15	338	341	351	374	406
16	307	303	312	194	325
18	359	345	328	475	399
19	489	512	434	385	477
20	507	539	541	444	581

Table D3   The accuracy estimated from field measurements at 18 test sites. Four mobile instruments compared to the hand-held measurements using the LTL-2000.

Instrument	R_L	ΔR_L	ε_{acc}
LTL-2000	306	-	-
Mob. Instr. 1	296	- 11	- 2.7 %
Mob. Instr. 2	298	- 8	- 3.1 %
Mob. Instr. 3	371	+ 65	+ 30.2 %
Mob. Instr. 4	333	+ 26	+ 10.8 %

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Table D4   *The precision estimated from field measurements at 18 test sites. Four mobile instruments compared to hand-held measurements using the LTL-2000.*

Instrument	R_{Lharm}	$\left|\Delta R_{Lharm}\right|$	ε_{prec}
LTL-2000	306	-	-
Mob. Instr. 1	306	30	9.8 %
Mob. Instr. 2	306	17	5.7 %
Mob. Instr. 3	306	69	24.6 %
Mob. Instr. 4	306	30	11.2 %

Table D5   *The uncertainty estimated from field measurements at 18 test sites. Four mobile instruments compared to the hand-held measurements using the LTL-2000.*

Instrument	R_L	$\left|\Delta R_L\right|$	ε_{unc}
LTL-2000	304	-	-
Mob. Instr. 1	271	45	10.2 %
Mob. Instr. 2	294	19	6.1 %
Mob. Instr. 3	362	88	38.3 %
Mob. Instr. 4	326	34	13.1 %

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Annex E

Measurement locations

1. _Measurement point MP1: Tervurenlaan in Tervuren, edge line_

2. _Measurement point MP1L: Tervurenlaan in Tervuren, centre line_

3. _Measurement point MP2: Meerdaalboslaan in Leuven, edge line_

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4. _Measurement point MP3: N227b-Steenokkerzeel, edge line_

5. _Measurement point MP4L: N21 – Nieuwe Haachtse Steenweg – Machelen, centre line_

6. _Measurement point MP4: N21 – Nieuwe Haachtse Steenweg – Machelen, edge line_

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7. *Measurement point MP5: Brusselsesteenweg-Zemst, edge line*

8. *Measurement point MP6: N227 Mechelsesteenweg-Wezembeek-Oppem, edge line*

9. *Measurement point MP7: N227 Tervuursesteenweg-Hofstade, edge line*

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10. *Measurement point MP8: N270 Rubenslaan-Zemst, edge line*

11. *Measurement point MP9: N25 Naamsesteenweg-Oud-Heverlee, edge line*

12. *Measurement point MP10: E40-Hoegaarden, edge line*

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13. *Measurement point MP11: E40-Oud-Heverlee, edge line*

14. *Measurement point MP12: E40-Bierbeek, edge line*

15. *Measurement point MP13: E314-Leuven, edge line*

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16. Measurement point MP14: E19-Vilvoorde, edge line

17. Measurement point MP15: E19-Zemst, edge line

18. Measurement point MP16: E19-Vilvoorde, edge line

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19. Measurement point MP17: E19-Machelen, edge line

20. Measurement point MP18: Haachtsesteenweg-Kampenhout, edge line

21. Measurement point MP19: E19-Mechelen, edge line

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22. *Measurement point MP20: entry E19-Mechelen, edge line*

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