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The performance of wet visibility road markings – final report on Provväg 1998 – 2000

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Abstract (background, aims, methods, results) max 200 words:

In a field test, the function of road markings, primarily with regard to their retroreflective properties in the wet state, was tested.

A total of 39 road markings, visible in the wet, were studied on two test sections. Measurements of retroreflective properties (dry and wet), luminance coefficient and friction, and assessments of the state of wear, were made on four occasions over a two year period.

A study was also made in a separate measurement series, in winter conditions, of the retroreflective properties of road markings on days determined in advance. In this way, weather conditions were random, and the results of these measurements may be said to represent the visibility of road markings on typical winter days in central Sweden.

In the report, comparisons are also made between the function of road markings (their visibility in the dark) and the requirements which, according to COST 331, should be specified with reference to the needs of road users.

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Foreword

This study was initiated and commissioned by the Swedish Road Administration, and financed jointly by the Administration and the participating firms. The 11 firms that took part in the experiment paid for laying their own test markings and, in principle, half the cost of the physical measurements on these. The Swedish Road Administration defrayed the cost of the other half of the measurements and the cost of the planning, analysis and documentation of the study.

The project manager for the Swedish Road Administration/VÄG was **Jan-Erik Elg.**

The persons responsible for arranging the test sections were Per-Ola Mattsson in **Region West** and Berndt Söderholm in **Region Mitt**.

The physical measurements were performed by VTI, LG RoadTech and Inger Friborg Konsult. Most of the optical measurements were made by Göran Nilsson, LG RoadTech, Lars-Erik Svensson, LG RoadTech, Uno Ytterbom, VTI, Ib Lauridsen, VTI, and the undersigned. Sven-Åke Lindén, VTI, was responsible for friction measurements.

The sections of the report which deal with laboratory measurements were written by **Sofi Åström**, while the undersigned is responsible for the remainder.

I wish to thank all those taking part who worked in all possible and impossible weather conditions.

Linköping in October 2001

Sven-Olof Lundkvist
Project Manager

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The performance of wet visibility road markings — final report on Provväg 1998-2000

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Summary

Technically, it is possible to manufacture road markings that have considerably better retroreflective properties in the wet than those in the market

The poor visibility of road markings in the dark and wet is a well known problem. In rainy weather, a reflective water surface is often formed on the surface of road markings, with the result that the light from the vehicle is reflected away from, instead of towards, the vehicle. This is the reason that conventional flat road markings can be hardly seen in the dark when it rains.

In a European project (COST 331) it has been stated that longitudinal road markings should be visible not less than 45 m in front of the vehicle on a road subject to a 90 km/h limit if driving is to be safe and comfortable. In wet conditions, a flat marking has a considerably shorter visibility distance and cannot be regarded to satisfy the requirements that road users can pose for safety and comfort. Can these requirements be met using road markings which have been specially designed to have good visiblity in dark and wet conditions?

In order to answer this question, a number of firms were invited to apply road markings, visible in the wet, on two test sections. No limits were imposed on the type of road marking to be laid, although the function was to focus on good visibility in the dark and wet.

The road markings were laid on the test sections in August 1998, and physical measurements of retroreflective properties (dry and wet), luminance coefficient and friction were made on four occasions up to May 2000. Further measurements of retroreflective property were also made on ten occasions.

Measurements on wet road markings showed that these can be made so that retroreflection initially exceeds 200 mcd/m^2/lux. Function deteriorates over time, in such a way that for most materials it drops to about half this value after two winters. These results must be regarded very good, and can be compared with the requirements specified in the Nordic countries – 25-35 mcd/m^2/lux.

A comparison with the results from COST 331, Chapter 5, shows that visibility in the dark and wet would initially have been ca 70 m for the best materials if they had been made as the "ordinary" Swedish edge marking, i.e. intermittent with a width of 0.10 m. Visibility deteriorated over a two year period to 55-60 m. This implies that they would satisfy the requirements for the absolutely shortest preview time according to COST 331. Whether they meet the requirements for the

desired comfort is more doubtful. In this respect, COST 331, Chapter 6, states that 55 m is far too short a visibility distance if the speed limit is 90 km/h.

The results can thus be summarised as follows:

- Technically, it is possible to manufacture road markings that have considerably better retroreflective properties in the wet than those in the market at present.

- Even if these road markings, visible in the wet, are laid it is doubtful if the requirement concerning comfort for the conventional Swedish intermittent edge marking is satisfied.

If a visibility distance longer than 55 m is to be achieved in the wet, the edge marking must therefore have a greater aggregate area, i.e. it has to be wider or have closer spacing, or be continuous.

1 Background and aim

In order to make driving easier and to improve visibility, roads are provided with markings. In daylight, and often also in the dark if the carriageways are dry, the visual task is relatively simple, and in such a case the primary purpose of road markings is to define lanes and to guide traffic in the correct direction, for instance at intersections. But during the winter months the carriageways are often wet and/or dirty, which causes a considerable deterioration in the visibility of the road and increases the need for visual aids. But it is precisely in such conditions that it has always been difficult to maintain the visibility of road markings.

Recent research within COST 331 (1999) has demonstrated the need for road markings to be visible under *all* visual conditions. In this project it was decided to make use of the term *pre-view time* to describe visibility. This quantity is the product of visibility in metres and speed in m/s, and is thus a way of expressing visibility as a function of speed. This must be seen to be reasonable, and implies that, for a given minimum visibility, the speed must be adjusted in order that the driver should be able to keep the vehicle on the road.

In Chapter 5 of COST 331 it was found that an **absolute minimum level** of pre-view time for safe driving is 1.8 second. With a lower pre-view time the driver finds it difficult to keep the vehicle in the lane. It was further found, in Chapter 6, that a pre-view time of 2.2 seconds is far too short for comfortable driving. Previous studies (Johansson & Rumar) give 3 seconds as the lowest level of pre-view time.

Models for the visibility of road markings were also produced and validated within the above COST project. This means that if the retroreflective properties, width and spacing of road markings are known, it is possible to calculate their visibility. And if the speed of the vehicle is also known, the pre-view time can be determined.

- ***The visibility of a road marking in the dark, when illuminated by the lights of a vehicle, is described both by its retroreflective properties, expressed in mcd/m²/lux, and by its area.***

- ***If the road marking is seen at a distance of S metres and a vehicle is driven at a speed of v m/s, the pre-view time of the driver will be S/v second.***

- ***One requirement is that in all conditions – including the dark and rain – the pre-view time should be at least 2 seconds and preferably up to 3 seconds.***

Table 1 shows what a pre-view time of 2 seconds means for the visibility and retroreflective properties of road markings. For this table, the input values in the model produced in COST 331 are as follows: the vehicle has its headlights on main beam, the lights are a little dirty, the driver is about 50 years old and is slightly dazzled by the surrounding light sources. It is further supposed that the carriageway is wet, with retroreflection of 5 mcd/m²/lux.

Table 1 *Requirements for the visibility and retroreflection of longitudinal road markings in vehicle lights, assuming that the pre-view time shall be 2 seconds and that the vehicle is driven at the current speed limit on a wet carriageway. Visibility and retroreflective properties calculated with the model produced in COST 331.*

Type of marking	Speed limit	Visibility (m)	Retroreflection (mcd/m^2/lux)
intermittent edge marking (1+2), 10 cm wide	70 km/h 90 km/h 110 km/h	58 75 92	40 80 160
continuous edge marking, 10 cm wide	70 km/h 90 km/h 110 km/h	58 75 92	25 45 80
continuous edge marking, 20 cm wide	70 km/h 90 km/h 110 km/h	58 75 92	20 35 55
continuous edge marking, 30 cm wide	70 km/h 90 km/h 110 km/h	58 75 92	18 30 50

In Sweden and other countries, requirements have been in force for a long time regarding the retroreflective properties of dry road markings and thus their visibility when illuminated by the lights of a vehicle. On the other hand, there have been no requirements so far regarding the performance of wet road markings, in spite of the fact that visibility in the wet and dark is at least as important as in other, better visibility conditions. One reason for the absence of these requirements is that it has been difficult to produce road markings which have good visibility in the wet. The industry has however made progress, and it has been felt that it was desirable to find what performance in the wet can be achieved with today's technology.

It is seen from Table 1 that on the typical Swedish road subject to a speed limit of 90 km/h, with intermittent edge markings, retroreflection must be ca 80 mcd/m^2/lux in order that the requirement of a pre-view time of 2 seconds should be satisfied. Conventional flat markings have no chance of satisfying this requirement in the rain. Is it at all possible to produce markings that have a sufficiently high retroreflection in the wet? The primary aim of this study was to find what performance wet road markings can achieve.

A secondary aim was to investigate what performance can be expected on a typical winter day. Measurements were therefore made on 10 predetermined occasions regardless of weather conditions.

2 Method

2.1 Test sections

The firms which indicated that they were interested to take part in the study were given a free hand to lay wet visibility road markings on two 8 m wide test roads. One of the test sections was on Road 63 just to the north of Molkom, while the other was situated on Road 301 between Rättvik and Furudal. The first road had a completely new and smooth asphalt concrete surfacing, and the other had a new surface dressing of very coarse texture; stone size was 12-16 mm.

Each test marking was laid as a 20 cm wide continuous edge line on both sides of the road over a 200 m long section. Placing along the road was decided by drawing lots, although the lot was controlled so that different types of road markings of the same make were adjacent to one another. In order to reduce any effects due to bends, the same types of road marking were at all times laid on both sides of the road, opposite one another, so that a test marking that happened to be laid on a bend was always on a left-hand bend on one side of the road and on a right-hand bend on the other side. The principle is shown in Fig. 1 below. Figs. 2 and 3 show the test roads – Road 63 in Värmland and Road 301 in Dalarna.

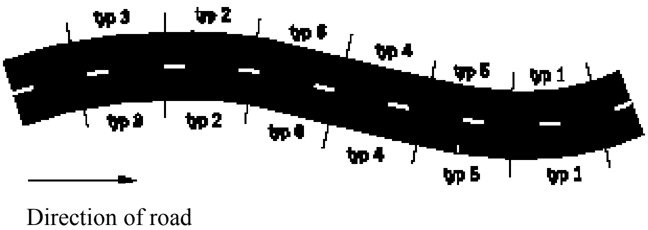

Figure 1 *Principle of test section arrangement. The figure shows how the placing of the six test markings along the road was decided by drawing lots.*

Figure 2 *Appearance of test section on Road 63 when newly laid, autumn 1998.*

Figure 3 *Appearance of test section on Road 301 when newly laid, autumn 1998.*

Both test roads have an AADT of ca 2000 vehicles/day and a width of 7.0 – 8.5 m. The road in Värmland is treated with salt while Road 301 is hardly salted at all. Both are ploughed with a steel blade.

2.2 Test markings

A total of 11 firms signed up for the project. One withdrew later on, so that 10 firms finally took part. These manufacturers laid a total of 19 test markings on Road 63 and 18 on Road 301. A reference marking was also laid on each test road; a conventional flat thermoplastic marking on the asphalt surfacing in Värmland, and a sprayed plastic marking on the surface dressing in Dalarna. All manufacturers except Svensk Fog applied their markings in August 1998, and Svensk Fog in September in the same year. At the time of application the weather was good and the carriageways completely dry. The products laid are listed in Tables 2 and 3. In these tables and also in the rest of this report the following codes have been used:

C	***Cleanosol, Kristianstad***
EA	***EAB, Gävle***
EK	***EKC, Hallsberg***
G	***Geveko, Göteborg***
J	***Jocett, Norsborg***
N	***Nor-Skilt, Moss, Norway***
SF	***Svensk Fog, Kramfors***
SV	***Skandinavisk Vägmarkering, Norsborg***
T	***Teknos, Tranemo***
REF	***Reference marking***
1-6	***Serial number for each make***
S	***Värmland County***
W	***Dalarna County***

The code G2W thus denotes the Geveko test marking No 2, applied in Dalarna County. G2S denotes the same product on the test road in Värmland County.

Table 2 *Description of the test markings which are applied on Road 63. Direction from south to north, i.e. from Molkom towards Filipstad.*

Code	Type	Manufacturer's designation	Appearance
REFS	extruded	Cleanosol 6731	flat
G1S	waterborne paint	Mercalin K-829/1	flat
G2S	waterborne compound	G2	textured
EA1S	spray	F622W	flat
C2S	extruded	X175-296	Longflex
C3S	extruded	X175-296	Longflex
C1S	extruded	6731	Longflex
V1S	extruded	F122W	filled Longflex
V2S	extruded	F729W	Longflex
N1S	extruded	F122W	chequer patterned
N2S	extruded	F729W	chequer patterned
T2S	cold plastic	Teknos 2-K	Longflex
T1S	paint	Test EL17	Longflex
EK2S	cold plastic	MetroMark CoPolymer	flat
EK1S	extruded	SRN 98	Longflex
SF1S	extruded	SF1	Kamflex
SF3S	extruded	SF177-489	Longflex
SV2S	spray on extruded	F-SP140 på F-SVR40	flat
SV1S	spray on extruded	F-SP140 på F-SVR40	chequer patterned
J1S	extruded	F-SVR40	chequer patterned

Table 3 *Description of the test markings which are applied on Road 301. Direction from south to north, i.e. from Rättvik towards Furudal.*

Code	Type	Manufacturer's designation	Appearance
C6W	spray/extruded*	X177-475/X177-475*	flat
C4W	spray	X175-296	flat
C5W	spray on extruded	X175-296 på X175-296	filled Longflex
J2W	extruded	F-SVR40	Longflex
EK2W	cold plastic	MetroMark CoPolymer	flat
EK3W	cold plastic on extruded	MMCP på SRN98	filled Longflex
SF3W	extruded	SF177-489	Longflex
SF2W	extruded	SF2	Kamflex
T2W	cold plastic	Teknos 2-K	Longflex
SV2W	spray on extruded	F-SP140 på F-SVR40	flat
SV3W	spray	F-SP140	flat
REFW	spray	Nor-Skilt E320W	flat
N1W	extruded	F122W	chequer patterned
N2W	extruded	F729W	chequer patterned
G2W	waterborne compound	G2	textured
G1W	waterborne paint	Mercalin K-829/1	flat
EA1W	spray	F622W	flat
V3W	extruded	F729W	textured
V4W	extruded	F122W	textured

* the extruded part nearest the centre of the road

It is seen from Tables 2 and 3 that some manufacturers decided to lay different materials on the two test roads. Others laid identical materials on the asphalt surfacing and the surface dressing, but because of the large difference in texture between these surfacings, the road markings nevertheless functioned differently in some respects.

Figure 4 shows a selection of the road markings in close-up. Broadly speaking, this selection represents the types laid on the test roads.

Figure 4 *A selection of the test markings on Road 63. This is a representative selection of the different types laid on both test roads. Photographer: Timo Unhola, VTT, Finland.*

As will be seen in Fig. 4, most of the test markings are corrugated. This has been the usual method employed so far to enhance wet visibility. Some of the test markings incorporate large reflective glass beads which may also be a way of improving performance in the wet.

2.3 Measurement of performance

2.3.1 Physical measurements

Checks on performance involved measurement of the parameters proposed in ATB VÄG, previously called VÄG 94:

- Retroreflectance value of dry marking (mcd/m^2/lux)
- Retroreflectance value of wet marking (mcd/m^2/lux)
- Luminance coefficient of dry marking (mcd/m^2/lux)
- Coefficient of friction of wet marking

The retroreflectance value and luminance coefficient were measured in accordance with SSEN 1436, i.e. in a geometry that simulates an observation distance of 30 m on the road. The first quantity was measured with an LTL-2000 reflectometer and the second with a Qd30. For measurements in the wet, the markings were wetted in accordance with the EN method, i.e. a large quantity of water was poured over the surface of the previously dry marking and there was a wait of ca 1 minute before the measurement was made.

In the case of most products, the coefficient of friction could not be measured in accordance with SSEN 1436 since this specifies measurement with the SRT pendulum. This instrument cannot be used on corrugated road markings, and all were therefore tested with PFT – Portable Friction Tester. As pointed out, PFT does not meet the requirement according to the EN standard, but has been validated in relation to the pendulum (Åström, H).

All measurements, both optical and friction measurements, were made in the direction of traffic.

2.3.2 The scope of measurements

Over the period autumn 1998 – spring 2000, two measurement series were performed:

1) On four occasions – 1998-09, 1999-05, 1999-08 and 2000-05, a ***comprehensive measurement of performance*** in accordance with VV Method Specifications 599 was carried out. This comprises measurement of retroreflection, luminance coefficient and coefficient of friction in accordance with 2.3.1. During these measurements, the carriageway and the road markings were at all times completely dry. For measurement of wet performance and coefficient of friction, they were wetted artificially.

2) On ten occasions – 1998-10, 1998-12, 1999-01, 1999-02, 1999-04, 1999-10, 1999-12, 2000-01, 2000-02 and 2000-04 – a **major measurement of retroreflection** in accordance with VV Method Specifications 599 was carried out. During these measurements, the road markings were measured in the state they had on a predetermined date. In this way, external conditions constituted a random variable.

At the time of the comprehensive measurement of performance, all parameters according to Subsection 2.3.1 were measured. During the major measurement of retroreflection, this parameter was measured on the road marking in the state it had on the predetermined date. The results from the 10 measurement occasions during the winter can thus be seen as the performance that can be expected on a "typical winter day" – if there is such a day at all.

In selecting the sites of measurement, VV Method Specifications 599 were complied with. Each section is 200 m long, but the first and last 10 m were not used. Measurement sites could thus be selected at random on a section of 180 m length. Such a section contains 15 measurement sites on each side of the road. For a comprehensive measurement, this implies that 4 sites were measured on each part section (right and left edge marking), and for a major measurement, 3 sites. The number of measurement points at each measurement site depends on the physical parameters to be measured. For further information regarding this, reference should be made to the Method Specifications of the Swedish Road Administration.

For the comprehensive measurement of performance, the readings can be compared with the requirements for the performance of road markings proposed in Regulations for Maintenance, Road Markings (RUV). It is presupposed that the test markings are applied on a road in Road Marking Class 3, i.e. it is the requirements for such a road that have to be met. This implies performance requirements according to Table 4.

Table 4 *Performance requirements proposed in Regulations for Maintenance, Road Markings (RUV) for longitudinal road markings on a road assigned to Road Marking Class 3. The unit for retroreflection and luminance coefficient is mcd/m²/lux, while friction is nondimensional.*

Retroreflection, dry marking	**100**
Retroreflecion, wet marking	**35**
Luminance coefficient, dry marking	**130**
Friction, wet marking	**45**

3 Results

3.1 Results of the comprehensive measurement of performance

3.1.1 General

If the directions in Method Specifications 599 of the Swedish Road Administration are complied with, each test marking is in actual fact laid on two part sections – left and right edge marking. In this project, these two edge markings were laid immediately after one another in time, and the external conditions must be considered to have been the same when one and the same material was laid. There are therefore good reasons to regard these two part sections as only one section. In the following, each test marking is therefore one part section, which implies that the comprehensive measurement was carried out at 8 measurement sites for each part section. This means, in turn, that the number of these measurement sites that fails a test must not exceed 1 (one) if the part section (road marking) is to be approved.

The results are set out in three parts:

- Mean values of retroreflection (dry and wet), luminance coefficient and coefficient of friction are tabulated for each test marking on the four measurement occasions.
- Curves of the mean values of the wet value of retroreflection, so that development over time can be seen.
- The number of approved measurement sites for each and every one of the four parameters according to Table 4, on the four measurement occasions.

It must be noted that approval according to the performance requirements is based on the mean values for each individual measurement site, not on the mean values set out in the following.

3.1.2 Mean values of retroreflection for dry road markings

The retroreflectance values of the dry road markings, on the four measurement occasions, are set out in Tables 5 and 6 for Road 63 and Road 301 respectively.

***Table 5** Retroreflectance values (mcd/m²/lux) for **dry** road markings on **Road 63** on the four measurement occasions, autumn 1998, spring 1999, autumn 1999 and spring 2000. Each value is a mean of retroreflection at 8 measurement sites, i.e. of 48 individual readings.*

Test marking	1998-09	1999-05	1999-08	2000-05
C1S	337	264	182	146
C2S	597	427	413	414
C3S	372	375	321	287
EA1S	307	244	268	240
EK1S	313	-	150	173
EK2S	601	-	111	97
G1S	472	278	292	209
G2S	316	194	178	191
J1S	560	405	373	292
N1S	345	254	312	259
N2S	258	258	305	333
REFS	273	356	407	232
SF1S	414	276	241	166
SF3S	313	275	204	219
SV1S	284	264	285	287
SV2S	379	378	402	354
T1S	319	205	185	189
T2S	188	134	130	119
V1S	475	300	367	296
V2S	371	265	298	272

Table 6 *Retroreflectance values (mcd/m²/lux) for* ***dry*** *road markings on* ***Road 301*** *on the four measurement occasions, autumn 1998, spring 1999, autumn 1999 and spring 2000. Each value is a mean of retroreflection at 8 measurement sites, i.e. of 48 individual readings.*

Test marking	1998-09	1999-05	1999-08	2000-05
C4W	466	251	228	247
C5W	399	279	231	243
C6W	463	223	193	213
EA1W	187	60	39	34
EK2W	197	-	51	45
EK3W	342	-	51	63
G1W	360	180	84	79
G2W	174	118	72	101
J2W	297	214	187	191
N1W	109	181	126	182
N2W	260	134	100	154
REFW	226	98	63	70
SF2W	430	293	141	129
SF3W	230	141	134	131
SV2W	325	336	312	327
SV3W	304	174	98	108
T2W	147	111	85	101
V3W	329	250	235	250
V4W	326	322	209	242

When reading Tables 5 and 6, it must be borne in mind that the primary aim was not to apply road markings of high retroreflectance values in the dry; the technology for doing that has been known for a long time. In spite of this, it is seen that most test markings had very high values.

3.1.3 Mean values of retroreflection for wet road markings

Tables 7 and 8 set out the mean values of the retroreflection of road markings in the wet state.

***Table** 7 Retroreflectance values (mcd/m²/lux) for wet road markings on **Road 63** on the four measurement occasions, autumn 1998, spring 1999, autumn 1999 and spring 2000. Each value is a mean of retroreflection at 8 measurement sites, i.e. of 48 individual readings.*

Test marking	1998-09	1999-05	1999-08	2000-05
C1S	63	40	31	30
C2S	252	157	145	137
C3S	255	221	162	136
EA1S	54	42	32	30
EK1S	44	-	28	10
EK2S	117	-	26	9
G1S	75	51	37	21
G2S	103	37	35	25
J1S	250	161	131	63
N1S	190	95	88	68
N2S	135	111	92	22
REFS	20	21	16	14
SF1S	109	64	54	28
SF3S	81	66	55	46
SV1S	95	66	73	49
SV2S	75	31	40	24
T1S	85	36	30	11
T2S	78	39	35	16
V1S	201	126	104	78
V2S	145	100	104	69

Figures 5 and 6 illustrate the results from Road 63 and Road 301 respectively, at the time immediately after laying and on the last measurement occasion

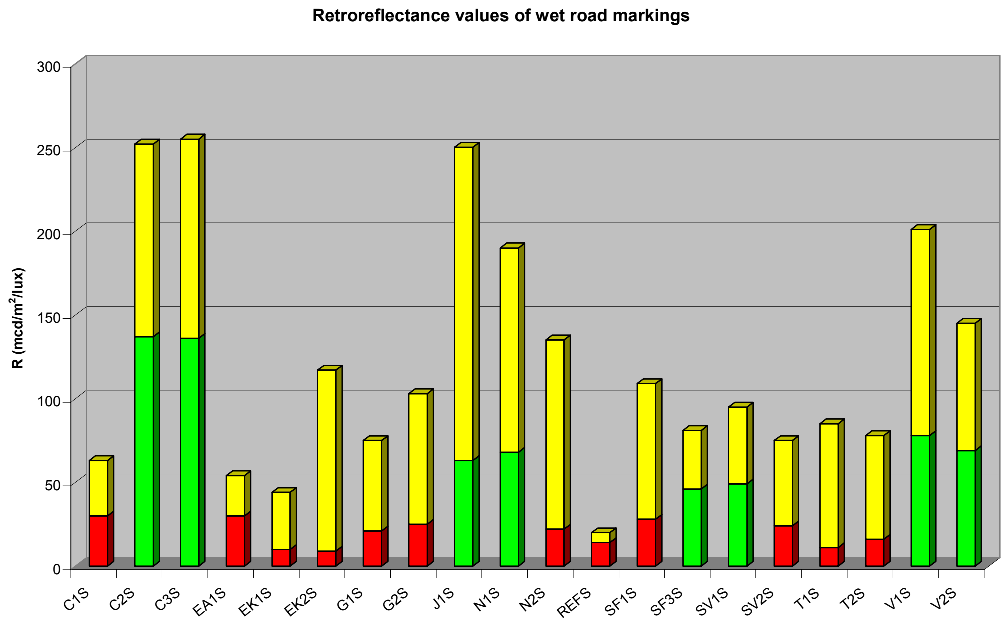

***Figure 5** Retroreflectance values (mcd/m²/lux) for wet road markings on **Road 63**, immediately after laying in autumn 1998 (yellow) and on the last measurement occasion, spring 2000 (green if $R_L \geq 35$, red if $R_L < 35$).*

***Table 8** Retroreflectance values (mcd/m²/lux) for wet road markings on **Road 301** on the four measurement occasions, autumn 1998, spring 1999, autumn 1999 and spring 2000. Each value is a mean of retroreflection at 8 measurement sites, i.e. of 48 individual readings.*

Test marking	1998-09	1999-05	1999-08	2000-05
C4W	175	89	76	47
C5W	223	161	141	112
C6W	149	105	97	53
EA1W	105	29	18	11
EK2W	82	-	25	20
EK3W	115	-	28	20
G1W	200	76	44	30
G2W	95	49	38	27
J2W	145	78	61	42
N1W	67	78	46	42
N2W	112	64	47	42
REFW	109	26	16	13
SF2W	124	86	43	37
SF3W	83	52	49	47
SV2W	120	59	42	37
SV3W	91	41	28	20
T2W	89	52	44	39
V3W	141	75	62	49
V4W	97	61	47	38

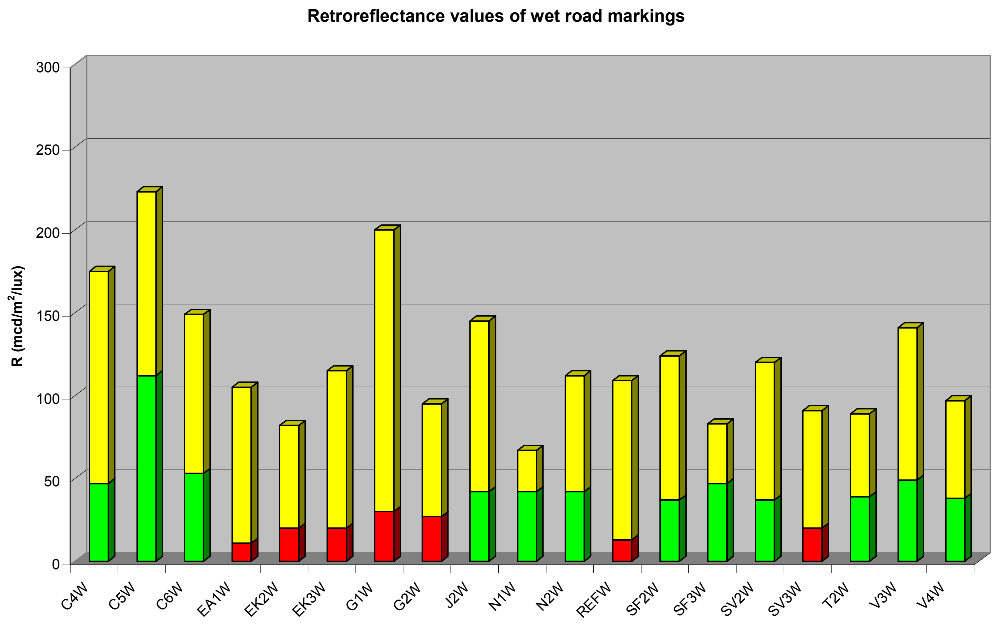

Figure 6 *Retroreflectance values (mcd/m²/lux) for wet road markings on Road 301, immediately after laying in autumn 1998 (yellow) and on the last measurement occasion, spring 2000 (green if $R_L \geq 35$, red if $R_L < 35$).*

The primary aim of the project was to test wet performance, i.e. to apply road markings that have a good performance in the wet over a period of at least 2 years – a usual guarantee period. Tables 7 and 8 show that this aim was satisfied throughout, especially on the asphalt surfacing on Road 63. Some test markings must be considered to have performed extremely well; even after two winters the wet values are higher than 50 mcd/m²/lux.

3.1.4 Mean values of luminance coefficient and wear for dry road markings

Tables 9 and 10 set out the values of the luminance coefficient (Qd value) for dry road markings, and also the wear after two winters.

***Table 9** Luminance coefficient (mcd/m²/lux) for **dry** road markings on **Road 63** on the four measurement occasions, autumn 1998, spring 1999, autumn 1999 and spring 2000. Each value is a mean of retroreflection at 8 measurement sites, i.e. of 24 individual readings. S indicates the proportion of the compound judged on the measurement occasion in 2000-05 to have been worn away.*

Test marking	1998-09	1999-05	1999-08	2000-05	S
C1S	185	171	181	159	0.00
C2S	164	155	157	160	0.00
C3S	153	150	149	146	0.00
EA1S	235	179	174	162	0.30
EK1S	193	-	162	172	0.00
EK2S	198	-	175	174	0.10
G1S	200	151	164	132	0.40
G2S	165	98	96	102	0.30
J1S	177	152	151	155	0.00
N1S	201	176	175	162	0.00
N2S	190	165	155	157	0.00
REFS	198	180	182	174	0.00
SF1S	213	189	174	193	0.00
SF3S	210	185	183	176	0.00
SV1S	222	180	173	164	0.00
SV2S	213	177	176	167	0.00
T1S	184	110	101	103	0.30
T2S	170	127	116	127	0.00
V1S	193	178	180	165	0.00
V2S	168	149	147	140	0.00

***Table 10** Luminance coefficient (mcd/m²/lux) for **dry** road markings on **Road 301** on the four measurement occasions, autumn 1998, spring 1999, autumn 1999 and spring 2000. Each value is a mean of retroreflection at 8 measurement sites, i.e. of 24 individual readings. S indicates the proportion of the compound judged on the measurement occasion in 2000-05 to have been worn away.*

Test marking	1998-09	1999-05	1999-08	2000-05	S
C4W	177	123	107	115	0,40
C5W	181	147	130	122	0,00
C6W	180	161	114	147	0,40
EA1W	178	71	63	62	0,90
EK2W	163	-	92	81	0,40
EK3W	189	-	106	89	0,40
G1W	183	92	85	85	0,40
G2W	161	95	72	75	0,50
J2W	168	103	83	93	0,30
N1W	196	146	115	109	0,30
N2W	191	135	102	106	0,50
REFW	195	111	83	86	0,50
SF2W	209	171	127	169	0,10
SF3W	164	122	121	129	0,30
SV2W	163	168	152	145	0,00
SV3W	195	105	82	83	0,50
T2W	126	99	75	88	0,30
V3W	180	100	128	122	0,30
V4W	177	153	158	158	0,00

It is seen in Table 10 that at the test section in Dalarna the test markings have relatively low Qd values. This is probably due to the coarse surfacing; for many types of road markings – especially paints and spyars – it was found difficult to cover the road surface.

On the smooth asphalt surfacing it is considerably better, with mean values that are in most cases in excess of the requirement, 130 mcd/m²/lux.

3.1.5 Mean values of coefficient of friction for wet road markings

Tables 11 and 12 set out the values of the coefficient of friction for the test markings. Note that, in accordance with VVMB 599, only one reading was taken at each measurement site.

Table 11 *Values of coefficient of friction for* ***wet*** *road markings on* ***Road 63*** *on the four measurement occasions, autumn 1998, spring 1999, autumn 1999 and spring 2000. Each value is a mean of the coefficient of friction at 8 measurement sites, i.e. of 8 individual readings.*

	Measurement occasion			
Test marking	**1998-09**	**1999-05**	**1999-08**	**2000-05**
C1S	0.61	0.75	0.89	0.83
C2S	0.48	0.56	0.59	0.66
C3S	0.46	0.51	0.53	0.59
EA1S	0.73	0.85	0.90	0.86
EK1S	0.63	-	0.79	0.87
EK2S	0.73	-	0.96	0.98
G1S	0.62	0.76	0.73	0.87
G2S	0.72	0.82	0.84	0.88
J1S	0.56	0.63	0.73	0.79
N1S	0.63	0.75	0.77	0.78
N2S	0.61	0.71	0.71	0.74
REFS	0.61	0.63	0.73	0.84
SF1S	0.62	0.75	0.76	0.86
SF3S	0.72	0.75	0.77	0.77
SV1S	0.67	0.75	0.78	0.78
SV2S	0.72	0.76	0.79	0.79
T1S	0.78	0.83	0.84	0.85
T2S	0.93	0.89	0.92	0.95
V1S	0.63	0.79	0.79	0.85
V2S	0.80	0.87	0.90	0.86

*Table 12 Values of coefficient of friction for **wet** road markings on **Road 301** on the four measurement occasions, autumn 1998, spring 1999, autumn 1999 and spring 2000. Each value is a mean of the coefficient of friction at 8 measurement sites, i.e. of 8 individual readings.*

Test marking	1998-09	1999-05	1999-08	2000-05
C4W	0.68	0.74	0.80	0.81
C5W	0.61	0.65	0.70	0.75
C6W	0.54	0.57	0.75	0.89
EA1W	0.84	0.87	0.89	0.92
EK2W	0.88	-	0.90	0.91
EK3W	0.84	-	0.90	0.91
G1W	0.78	0.85	0.90	0.90
G2W	0.84	0.84	0.86	0.90
J2W	0.81	0.83	0.85	0.88
N1W	0.74	0.79	0.84	0.84
N2W	0.76	0.78	0.82	0.85
REFW	0.80	0.87	0.89	0.91
SF2W	0.69	0.77	0.85	0.88
SF3W	0.79	0.84	0.80	0.82
SV2W	0.78	0.81	0.77	0.81
SV3W	0.71	0.72	0.88	0.91
T2W	0.91	0.87	0.88	0.89
V3W	0.82	0.80	0.83	0.85
V4W	0.75	0.77	0.79	0.82

There are hardly any problems as regards friction. It is only a few new test markings on Road 63 which have a coefficient of friction below 0.50. It can be seen that for almost all road markings – on both test roads – the coefficient of friction increases in time. This is in good agreement with experiences from previous measurements – in time, the coefficient of friction of the road marking approaches that of the carriageway. On the last measurement occasion, no road marking was below 0.50, which means that they would have satisfied the requirements proposed in ATB VÄG, even at pedestrian crossings.

3.1.6 Development of retroreflection over time

Figures 7–16 show how the retroreflection of wet road markings varied over time. In these figures, the curves for two test markings which are identical in Värmland and Dalarna are always in the same colour.

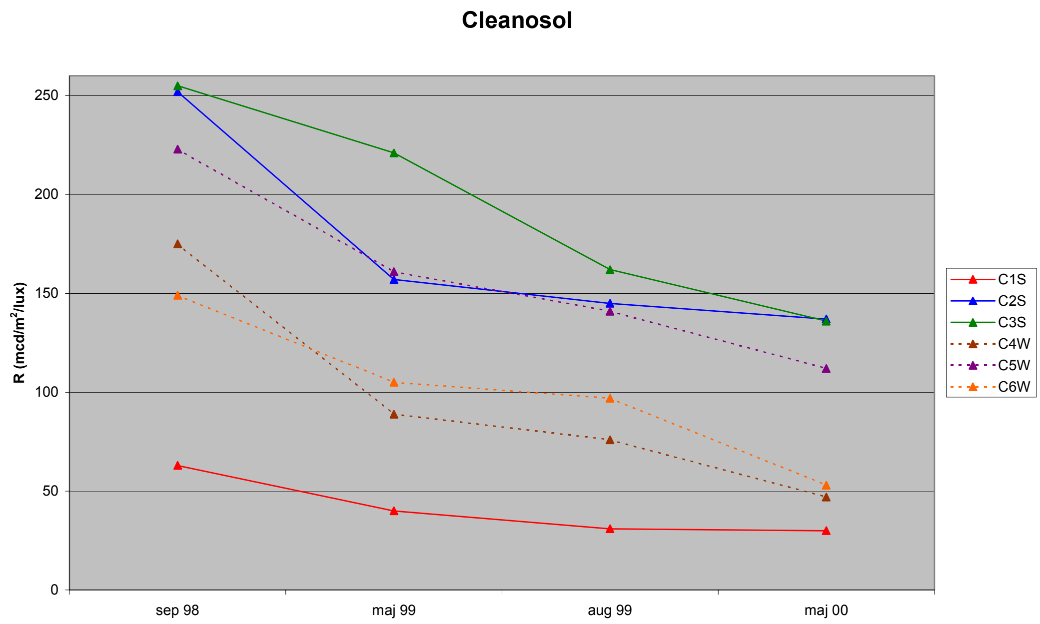

Figure 7 *Retroreflection for wet road markings on four measurement occasions in 1998-2000.* ***Cleanosol.***

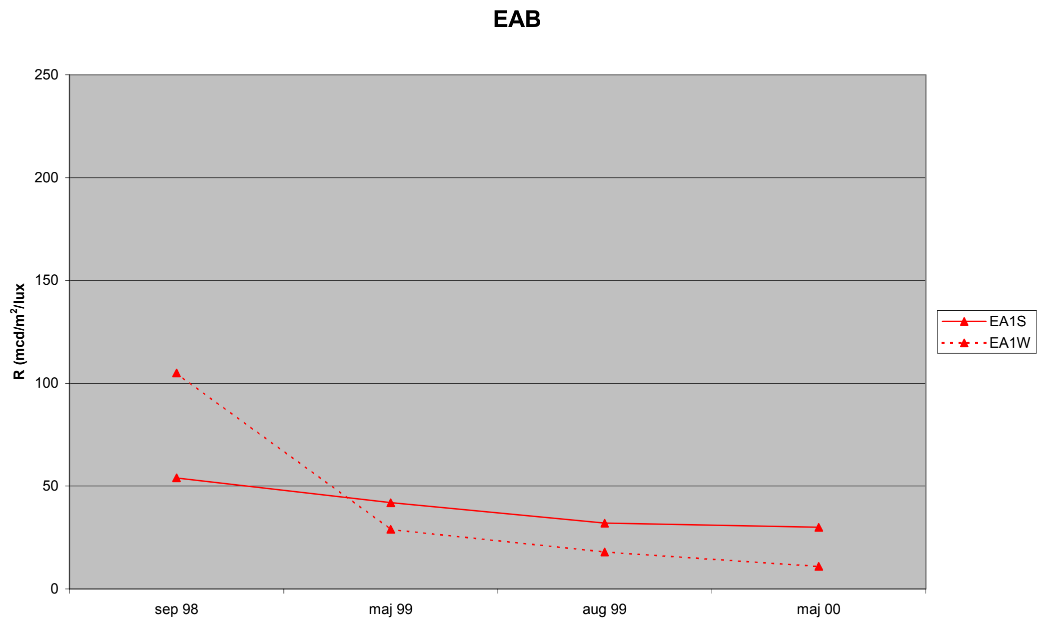

Figure 8 *Retroreflection for wet road markings on four measurement occasions in 1998-2000.* ***EAB.***

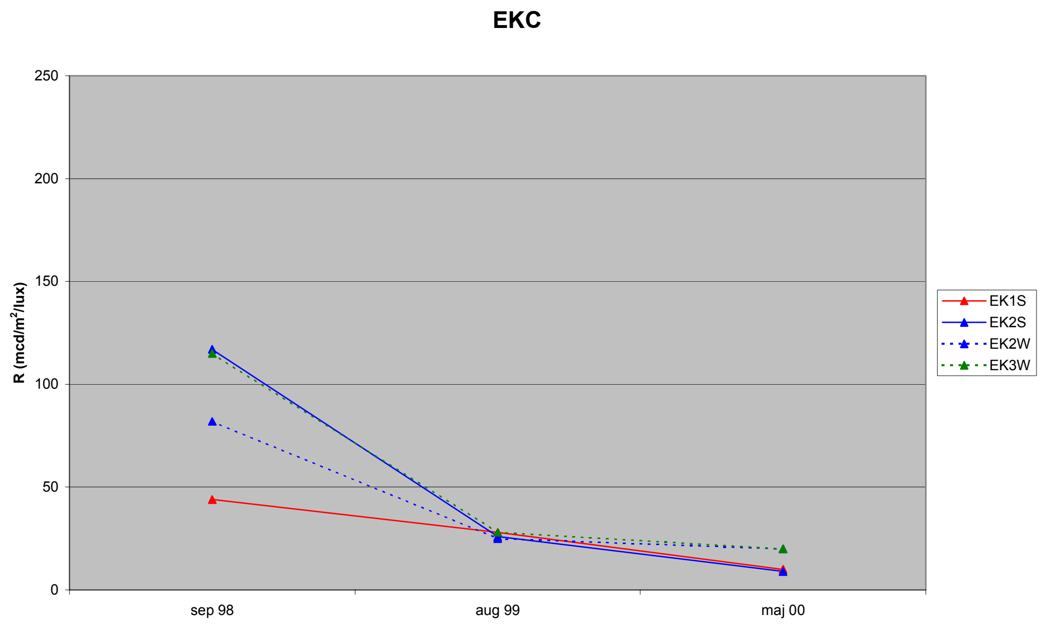

Figure 9 *Retroreflection for wet road markings on three measurement occasions in 1998-2000.* ***EKC.***

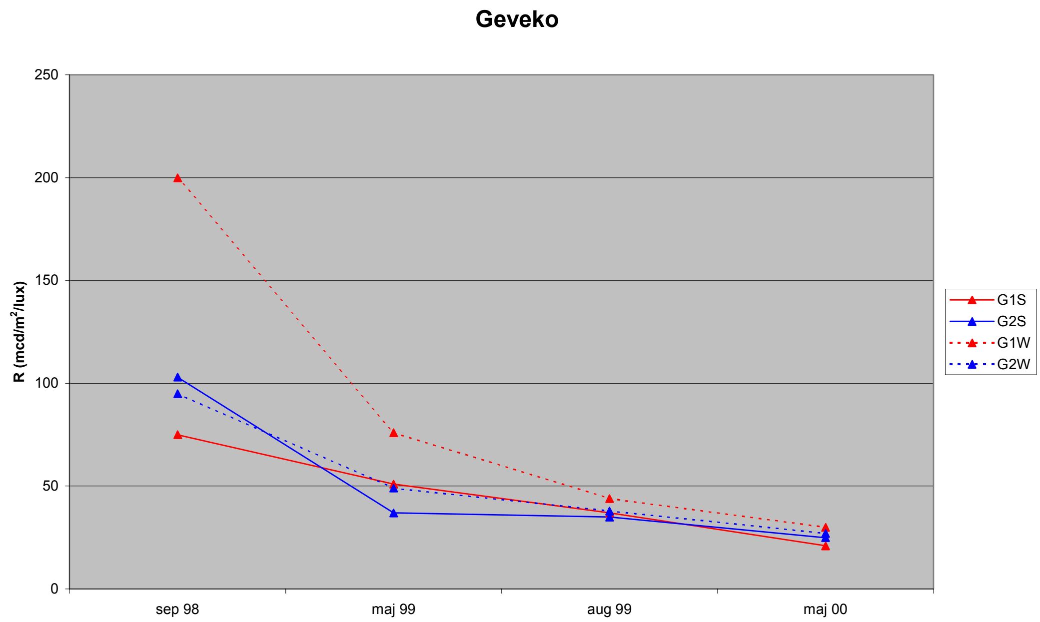

Figure 10 *Retroreflection for wet road markings on four measurement occasions in 1998-2000.* ***Geveko****.*

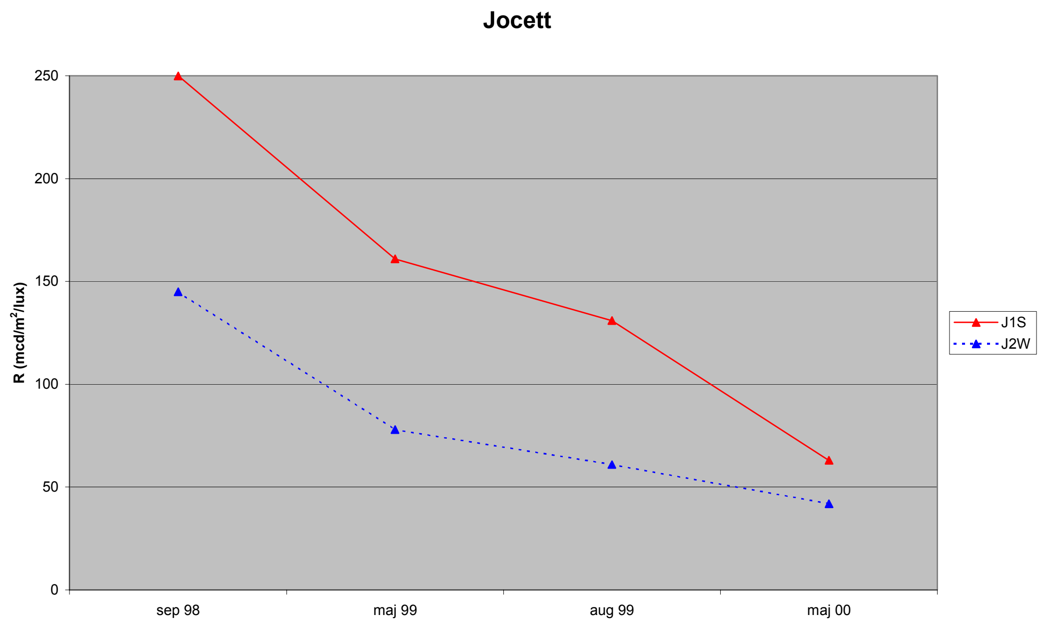

Figure 11 *Retroreflection for wet road markings on four measurement occasions in 1998-2000.* ***Jocett****.*

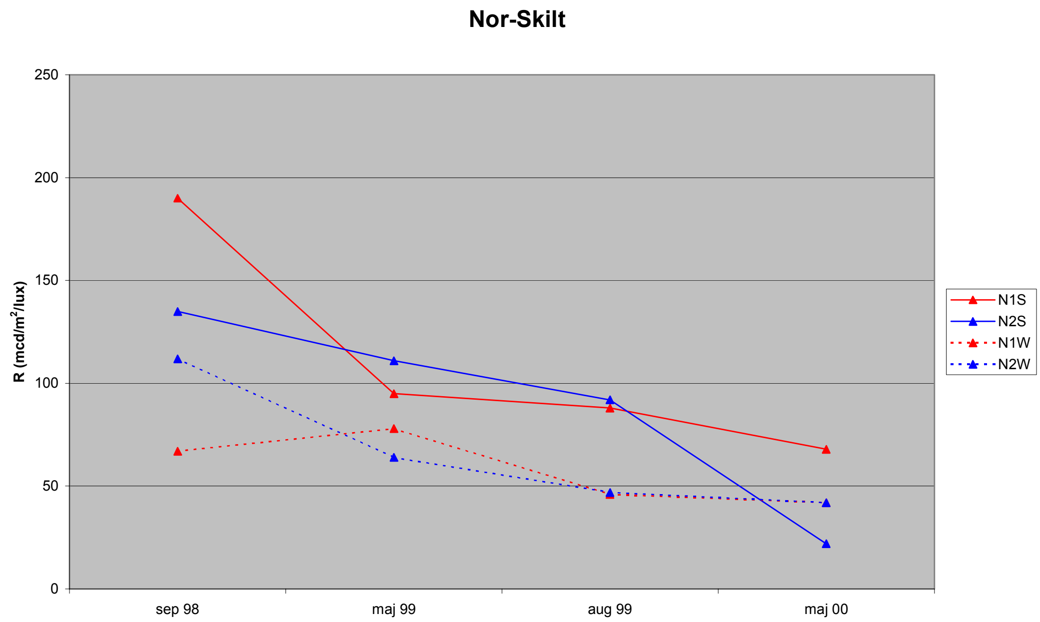

Figure 12 *Retroreflection for wet road markings on four measurement occasions in 1998-2000.* ***Nor-Skilt****.*

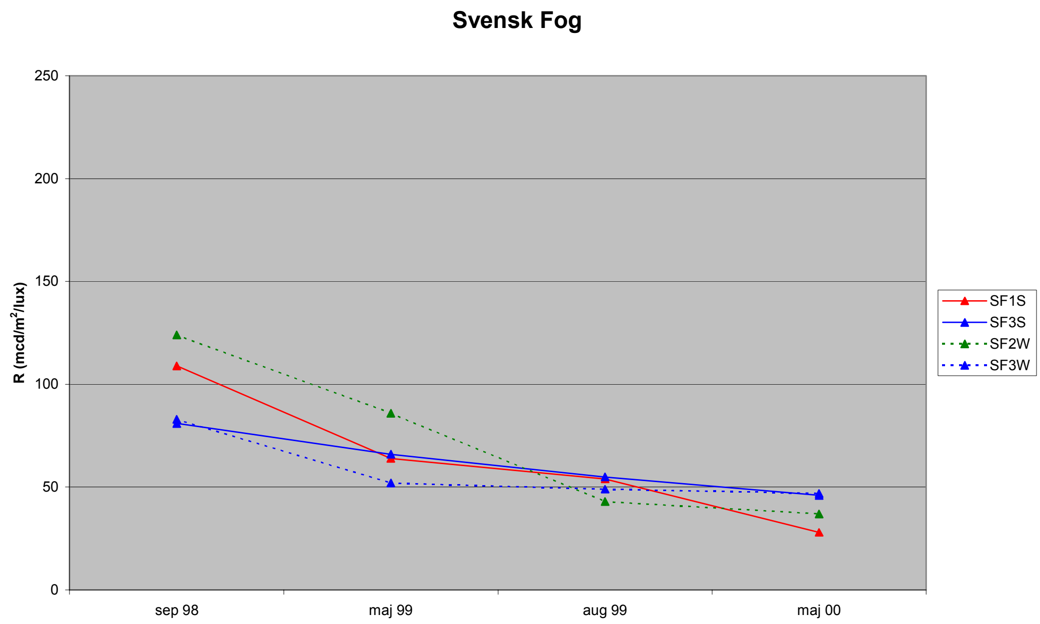

Figure 13 *Retroreflection for wet road markings on four measurement occasions in 1998-2000.* ***Svensk Fog****.*

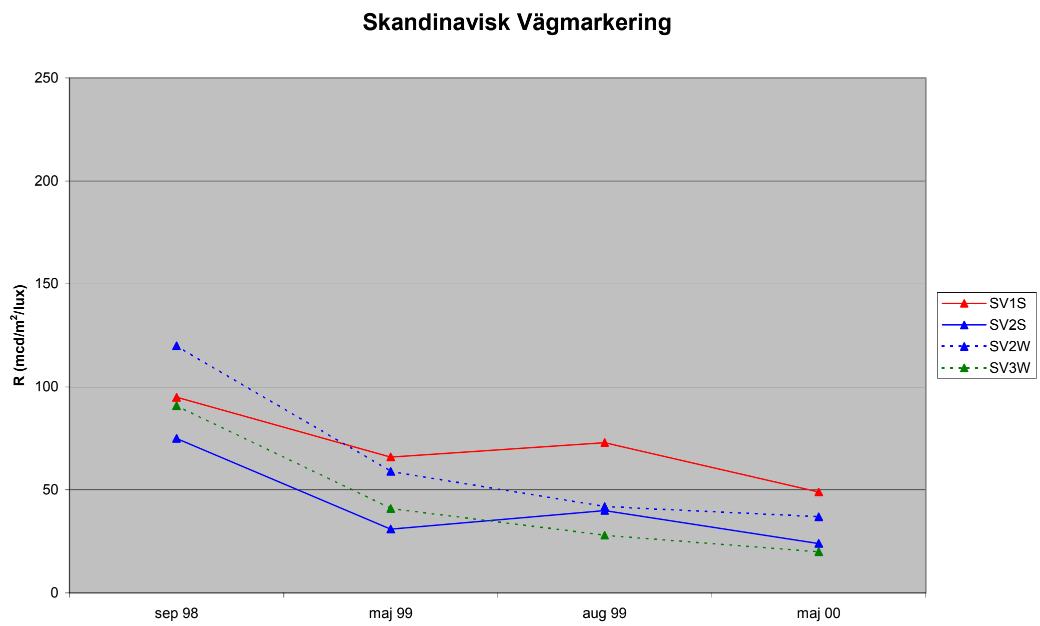

Figure 14 *Retroreflection for wet road markings on four measurement occasions in 1998-2000.* ***Skandinavisk Vägmarkering.***

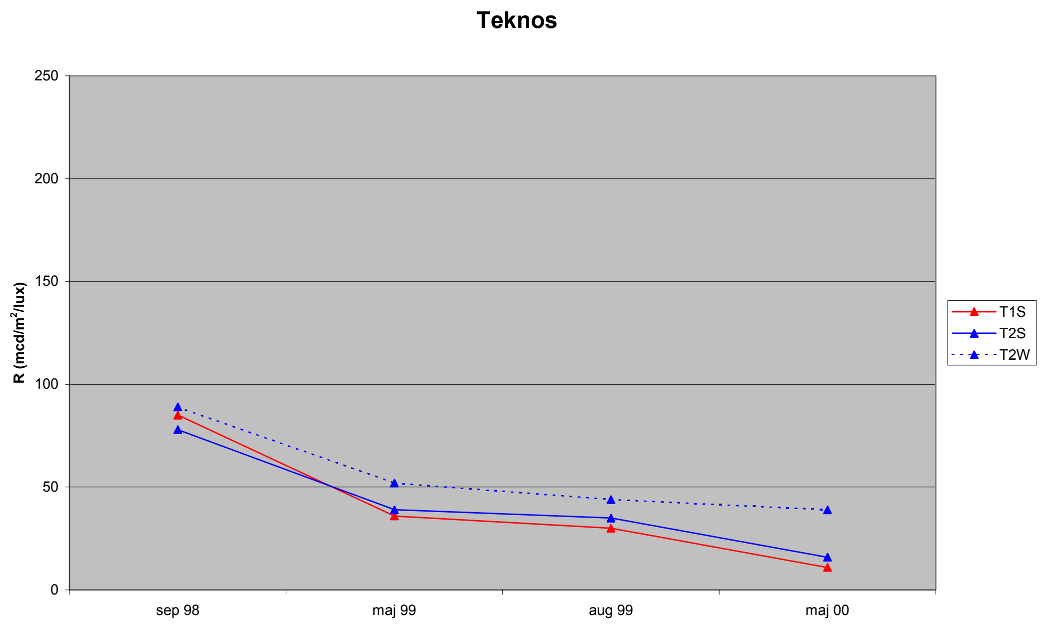

Figure 15 *Retroreflection for wet road markings on four measurement occasions in 1998-2000.* ***Teknos.***

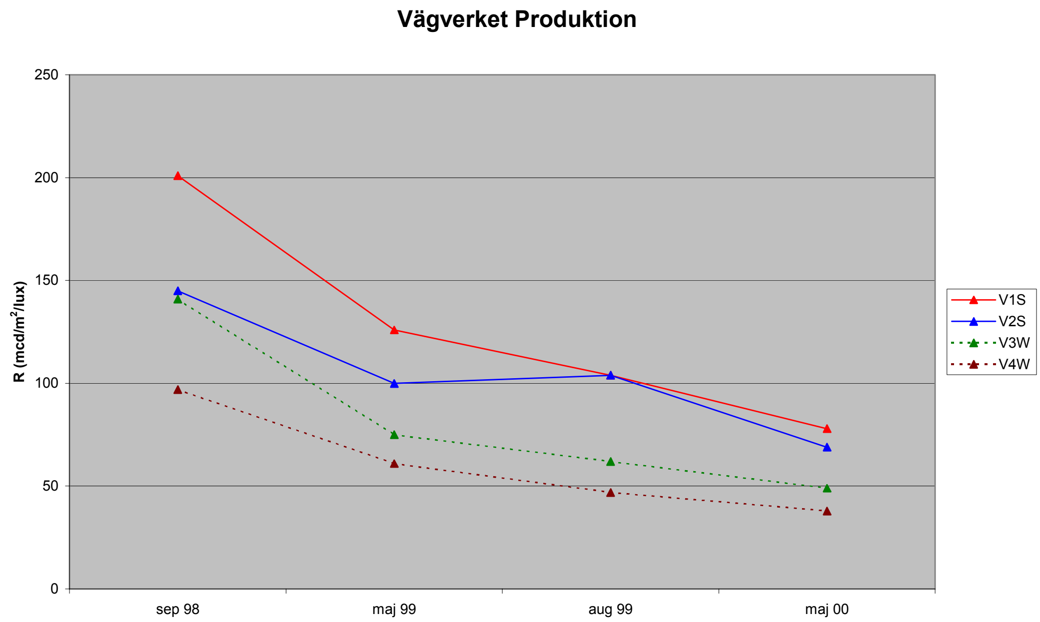

Figure 16 *Retroreflection for wet road markings on four measurement occasions in 1998-2000.* ***Vägverket Produktion****.*

It is seen from Figures 7 – 16 that the retroreflection of new wet road markings was in some cases very good. Even after two winters, several of the test markings still had good performance.

3.1.7 Tests of the performance of road markings in relation to proposed requirements

Tables 13 and 14 show which test markings would in the spring of 2000 have satisfied a test in accordance with the proposed performance requirements. The requirement in order that a road marking should be approved with respect to a physical parameter is that not more than 1 (one) of the eight measurement sites tested should have a mean value below the limiting value. This applies for each and every one of the parameters retroreflection/dry, retroreflection/wet, luminance coefficient and coefficient of friction. As regards wear, not more than 10% of the area of the road marking shall, according to RUV, have been worn away (on a road assigned to Road Marking Class 3).

Table 13 *Number of approved measurement sites (out of 8) on **Road 63** for each and every one of the parameters retroreflection for dry marking (R_t), retroreflection for wet marking (R_v), luminance coefficient (Qd) and coefficient of friction (μ). For wear (S), the proportion of marking area judged to have been worn away is given for each test marking, i.e. for all 30 measurement sites. A parameter which did not satisfy requirements according to RUV is coloured red.*

Test marking	R_t	R_v	Qd	μ	S	passed ?
C1S	8	3	8	8	0.00	no
C2S	8	8	8	8	0.00	yes
C3S	8	8	8	8	0.00	yes
EA1S	8	1	8	8	0.30	no
EK1S	8	0	8	8	0.00	no
EK2S	4	0	8	8	0.10	no
G1S	8	0	5	8	0.40	no
G2S	8	0	0	8	0.30	no
J1S	8	8	8	8	0.00	yes
N1S	8	8	8	8	0.00	yes
N2S	8	1	8	8	0.00	no
REFS	8	0	8	8	0.00	no
SF1S	8	0	8	8	0.00	no
SF3S	8	8	8	8	0.00	yes
SV1S	8	8	8	8	0.00	yes
SV2S	8	0	8	8	0.00	no
T1S	8	0	0	8	0.30	no
T2S	6	0	4	8	0.00	no
V1S	8	7	8	8	0.00	yes
V2S	8	8	7	8	0.00	yes
No. approved	18	8	16	20	16	8

It is seen from Table 13 that 8 of the 20 test markings satisfied a performance test in accordance with the proposed requirements in RUV. All the 12 which failed did so with respect to retroreflection in the wet state, and some also with respect to the luminance coefficient, retroreflection in the dry state and/or wear.

Table 14 *Number of approved measurement sites (out of 8) on* ***Road 301*** *for each and every one of the parameters retroreflection for dry marking (R_t), retroreflection for wet marking (R_v), luminance coefficient (Qd) and coefficient of friction (μ). For wear (S), the proportion of marking area judged to have been worn away is given for each test marking, i.e. for all 30 measurement sites. A parameter which did not satisfy requirements according to VÄG 94 is coloured red*

Test marking	R_t	R_v	Qd	μ	S	passed ?
C4W	8	5	0	8	0.40	no
C5W	8	8	1	8	0.00	no
C6W	0	8	8	8	0.40	no
EA1W	0	0	0	8	0.90	no
EK2W	0	0	0	8	0.40	no
EK3W	0	0	0	8	0.40	no
G1W	1	2	0	8	0.40	no
G2W	3	1	0	8	0.50	no
J2W	8	2	0	8	0.30	no
N1W	8	7	0	8	0.30	no
N2W	7	6	1	8	0.50	no
REFW	1	0	0	8	0.50	no
SF2W	4	3	8	8	0.10	no
SF3W	8	8	2	8	0.30	no
SV2W	8	5	6	8	0.00	no
SV3W	4	1	0	8	0.50	no
T2W	4	6	0	8	0.30	no
V3W	8	8	2	8	0.30	no
V4W	8	5	8	8	0.00	no
No. approved	9	5	3	19	4	0

The results from the test road with surface dressing are much worse than those from Road 63 with an asphalt surfacing. The explanation is that the texture of the surface dressing was very coarse, and many of the test markings therefore did not cover the road surface properly. This is the main reason that only three of the 18 test markings met the requirement for luminance coefficient.

Four test markings met both requirements for retroreflection – in both the dry and wet state. However, even these would not have been approved according to RUV since the requirement concerning luminance coefficient was not satisfied.

3.1.8 Comparison with the pre-view time requirement in COST 331

A comparison of the results in Tables 6 and 8 with the requirement for comfortable and safe driving according to the results of COST 331 shows the following:

If it is assumed that the speed limit is 90 km/h and the visibility of road markings is to be designed for this speed, it is found that a usual Swedish intermittent edge marking does not provide sufficient visibility in the wet. According to Table 1, retroreflection would have to be not less than 80 mcd/m²/lux, a value that only a few test markings achieve two years after application.

If, on the other hand, it is assumed that standard edge markings are continuous and 20 cm wide, a retroreflectance value of 35 mcd/m²/lux would be satisfactory.

All test markings would, when new, meet this requirement, even in the wet. After one winter, most markings would have satisfied this requirement, and even after two winters many satisfy the requirement.

The results thus show that an intermittent 10 cm wide edge marking almost never has sufficiently good visibility in the wet. However, it is possible to manufacture a road marking which, when applied as a continuous line and of 20 cm width, has a pre-view time of 2 seconds over a two year period.

4 Comments on the results

The measurements of performance on four occasions showed that it is possible to manufacture and apply road markings which meet the proposed requirements according to RUV – in any case, if they are applied on an asphalt surfacing.

On Road 63, the test road with an asphalt surfacing, the performance of many test markings was very good even after two winters. All the 8 markings which were approved during the performance measurement after two years were extruded thermoplastics, with corrugated surfaces. By far the most test markings satisfied the requirement concerning retroreflection in the dry, luminance coefficient, coefficient of friction and wear. On the other hand, there were problems regading retroreflection in the wet; initially, most had good wet performance, but due to the effect of the snow plough and other external factors, this function was often lost.

As mentioned before, the results from Road 301 with surface dressing are worse than those from Road 63. However, this road had a very coarse textured surface dressing, and it was found that for many materials coverage and also adhesion posed a problem. Some test markings managed to maintain their wet performance over the whole test period, but after two winters only three markings had an approved luminance coefficient. To a large extent, the reason that the others did not satisfy this parameter is wear; i.e. dark stones were left protruding from the surface and reduced the Qd value.

It should be borne in mind that the test sections have continuous edge markings, near the edge of the road. The results would probably have been different if, for instance, the test markings had been laid as intermittent lines on a 13 m wide road (with wide shoulders).

It should further be noted that, according to the proposed RUV (Regulations for Maintenance, Road Markings), a requirement concerning wet visibility will be imposed only on roads in Road Marking Class 3, i.e. on roads with AADT >4000. Such roads usually have asphalt surfacings, and the results from Road 63 must therefore be seen as both more interesting and more important than those from Road 301 with surface dressing.

If a more detailed explanation is needed why certain materials performed better than others, Fig. 17 will provide some guidance.

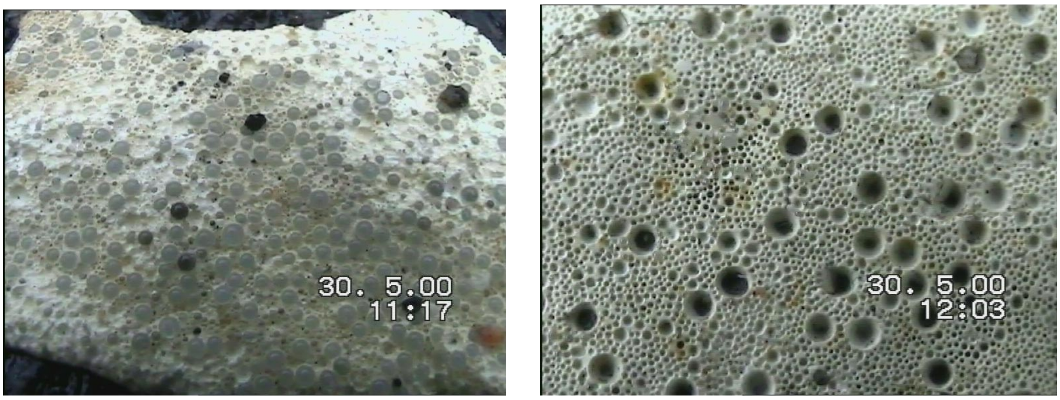

Figure 17 *Close-up of road marking materials J1S (at left) and EK2S (on right) on Road 63 in the spring of 2000. It is seen that in J1S the beads are still in place, while in EK2S there are only holes from which the beads had been displaced. Photographer: Bjørn Nossen, Nor-Skilt, Norway.*

The photographs in Fig. 17 were taken in May 2000, and a direct comparison can therefore be made with the retroreflectance values in Tables 5 and 7. In May 2000, retroreflection for a dry marking was 292 and 97 mcd/m^2/lux respectively for J1S and EK2S. These differences in performance are most probably explained by the difference in the number of glass beads in the surfaces. In turn, this difference is probably due to the binder used and/or to the coating of the bead.

5 Laboratory tests

In this chapter, the results for the parameters measured in the laboratory are set out.

Table 15 *Results of laboratory tests on the compounds used on the test roads. The make according to Section 2.2 is given in bold letters. After the name of the product, the letter N denotes normal thermoplastic compound, SP sprayed plastic, K cold plastic, and F paint. T denotes Tröger wear (g), ΔT difference in Tröger wear before and after ageing (g), S indentation value (sec), V adhesion (N/mm²), Y reflectance and ΔY difference in reflectance before and after ageing. Red denotes a parameter that did not satisfy the requirement according to the proposed ATB VÄG. Black cross hatching implies that the test is not relevant. "-" implies that the test was not performed.*

Product	in test marking	T	ΔT	S	V	Y	ΔY
C X175-296 N	C2S, C3S, C5W	0,2	-	745	2.0	0.81	-
C 6731 N	C1S	0,2	1,5	24	1.5	0.74	-0.04
C X177-475 SP	C6W	*	-	26	1.9	0.72	-
C X175-296 SP	C4W, C5W	0,2	0,2	745	2.0	0.74	+0.05
EK SRN 98 N	EK1S, EK3W	5,9	-	141	2.1	0.73	-
EK MM CoPol K	EK2S, EK2W				1.6	0.80	-
G Merk K-829/1 F	G1S, G1W				1.5	0.82	-
G G2 F	G2S, G2W	0,2	0,5		1.5	0.89	-0.02
N F729W N	N2S, N2W, V2S, V3W	1,6	*	185	1.8	0.78	-0.07
N F122W N	N1S, N1W, V1S, V4W	1,5	6,7	109	1.7	0.78	-0.06
N F622W SP	EA1S, EA1W	0,3	-	210	2.0	0.81	-
SF SF1 N	SF1S	0,2	*	28	1.7	0.76	-0.24
SF SF2 N	SF2W	0,4	3,1	52	1.9	0.75	-0.19
SF SF177-489 N	SF3S, SF3W	1,1	-	55	1.4	0.66	-
SV F-SVR40 N	SV1S, SV2S, SV2W, J1S, J2W	0,3	0,6	42	2.0	0.75	-0.12
SV F-SP140 SP	SV1S, SV2S, SV2W, SV3W	2,8	1,6	38	2.1	0.77	-0.08
T Test EL17 K	T1S	2,4	*		1.7	0.84	-0.03
T Teknos 2-K	T2S, T2W	5,2	-		1.3	0.75	-

* Test discontinued because of extreme wear

It is seen that not all materials were subjected to all the laboratory tests. The reason is that a parameter is not relevant for e.g. cold plastics (hatching), or that, with regard to ageing, the test was considered not to be meaningful ("-").

If the results from the test roads (Tables 13 and 14) are compared with the laboratory results, the following is found:

On **Road 63**, 8 test markings were approved. However, none of these was approved in the laboratory test: C2S and C3S did not meet the requirement for indentation value. None of the other six markings met the requirement concerning reflectance after ageing.

If wear on the test roads is studied, it is found that there are four test markings on **Road 63** which were not approved: EA1S (spray), G1S (paint), G2S (paint) and T1S (cold plastic). Of these, G1S passed the laboratory tests; for a paint, however, these relate only to adhesion and reflectance.

On **Road 301**, only four test markings (all of them extruded) satisfied the requirement concerning wear: C5W, SF2W, SV2W and V4W. However, none of these passed the laboratory test according to the proposals in the revised ATB VÄG.

It should be noted that on Road 63 it was C2S that had the best performance. After two winters, it had the following values (designations according to Table 13): R_t = 414 mcd/m²/lux, R_v = 137 mcd/m²/lux, Qd = 160 mcd/m²/lux, S = 0.00 and μ = 0.66, which is far above the requirement according to ATB VÄG and RUV. However, this material (X175-296) did not pass the laboratory test, and this product should not therefore form part of ordinary production.

6 Results of measurements in the winter

6.1 Retroreflection on 10 measurement occasions in the winter months

This chapter gives details of the retroreflection measurements made during the periods October-April 1998/99 and 1999/2000. It must be borne in mind that on some measurement occasions there were large variations along the test sections. A comparison of the different road marking types may, at least for some measurement occasions, be subject to systematic errors.

Table 16 gives a rough estimate of what conditions were like on the test sections on the 10 measurement occasions.

Table 16 *State of the road markings during the 10 retroreflection measurements performed during the winter months. The first date relates to measurements on Road 63 and the second to those on Road 301. Where several of the alternatives "dry", "moist", "wet" and "snow/ice" are given for the same dates, this denotes that the state of the markings varied along the test section.*

		Road 63				**Road 301**			
Meas.No.	Meas.date	dry	moist	wet	snow/ice	dry	moist	wet	snow/ice
1	1998-10-21/22		×				×		
2	1998-12-02/03		×				×		
3	1999-01-13/14				×				×
4	1999-02-24/25		×		×				×
5	1999-04-07/08		×	×			×	×	
6	1999-10-20/21	×				×			
7	1999-12-01/02	×					×		
8	2000-01-13/14		×	×				×	×
9	2000-02-24/25			×	×				×
10	2000-04-06/07	×				×			

It is seen from Table 16 that on Road 63 road markings were completely dry on three measurement occasions. On measurement occasion No 3, all road markings were covered by snow and/or ice.

On Road 301, road markings were dry on two measurement occasions, and on four all were fully or partly covered by snow and/or ice.

Figures 18 and 19 show the way retroreflection varied during the two winters on Road 63 and Road 301.

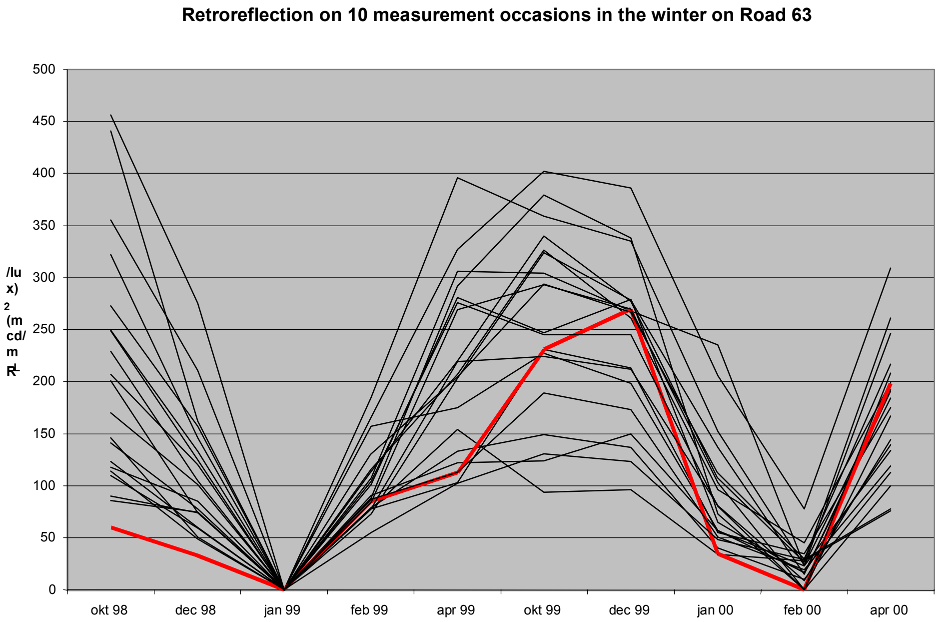

Figure 18 *Retroreflection (mcd/m²/lux) on Road 63 for 19 test markings (black) and the reference marking (red) during winters 1998/1999 and 1999/2000. Each value is based on 18 individual measurements.*

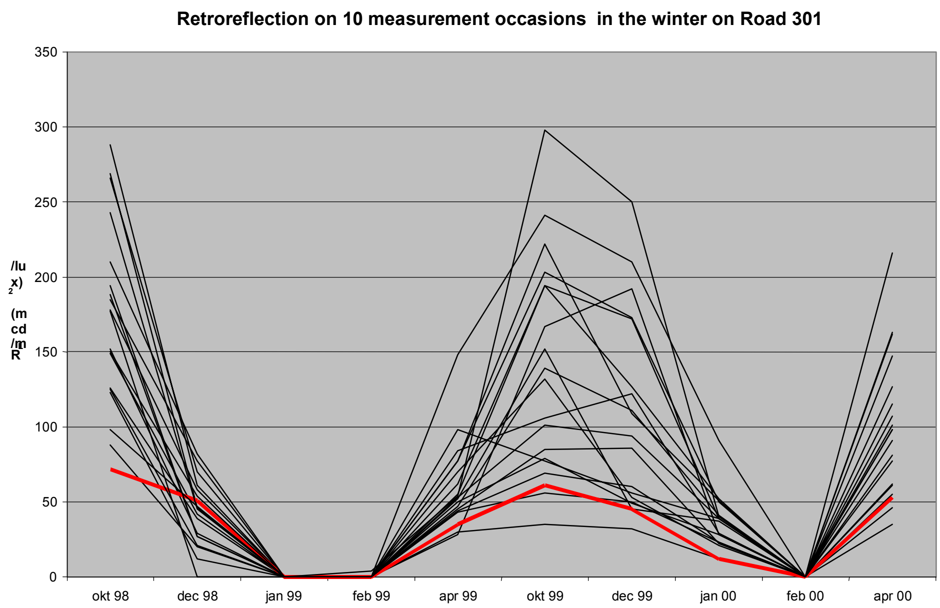

Figure 19 *Retroreflection (mcd/m²/lux) on Road 301 for 18 test markings (black) and the reference marking (red) during winters 1998/1999 and 1999/2000. Each value is based on 18 individual measurements.*

Figure 18 shows that, during the first winter, the reference marking on Road 63 which is a flat thermoplastic marking had a worse performance than most test markings. During the second winter its performance was slightly better in relative terms. On the occasions when the road markings were wet, the reference marking had a considerably lower retroreflectance value than most test markings.

On Road 301 the reference marking is a sprayed plastic. In relative terms, the performance of this was inferior to that of the reference on Road 63, and its performance on most measurement occasions was much worse than that of the test markings.

6.2 Performance during two winters

All road equipment must be available, i.e. satisfy a given function, during as much of the time as possible. As far as road markings are concerned, this means that they must satisfy the requirement specified for pre-view time during as much of the time as possible.

The European research project COST 331 demonstrated that 2 seconds is a far too short pre-view time for comfortable driving, and other studies suggest that it should be 3 seconds. *If* 3 seconds are specified as a desirable pre-view time, this implies that road markings shall have a retroreflectance value not less than ca **100 mcd/m²/lux**, provided that they are continuous and 0.20 m wide, and that the speed limit on the road is 90 km/h. A road marking that meets this requirement will in the following be considered to be *available.* The term ***availability T*** refers to the product of the proportion of road markings that meet the retroreflection requirement and the proportion of measurement occasions when the requirement of 100 mcd/m²/lux is satisfied. In other words: If 80% of road marking type A met the retroreflection requirement on 80% of the measurement occasions, then the availability T of road marking type A = 0.80 x 0.80 = 0.64.

In order to determine the availability of road markings, their performance (retroreflection) should be measured continuously, so that the proportion of the time during which the performance is below that required may be known. However, this is hardly a practical proposition. What must be done instead is to take a sample of days and make measurements on these; this is what has been done in this study.

For practical and economic reasons, the number of measurement days on each test section was limited to ten – all during the winter. On each of these occasions, measurements were made for each road marking type at six measurement sites selected at random. For each road marking, there is thus a measurement at 10 x 6 = 60 measurement sites and occasions. The performance at these randomly selected measurement sites and winter days has to describe *the availability of the road marking in the winter*.

The availability of all road markings is set out in Figs. 20 and 21 for Road 63 and Road 301.

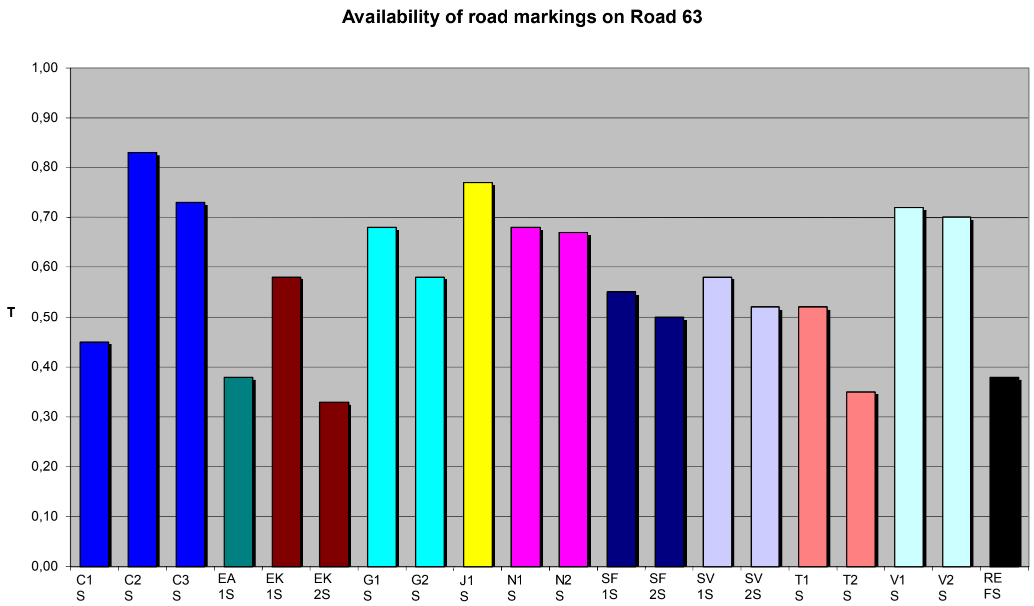

Figure 20 *Availability during winters 1998/1999 and 1999/2000 on Road 63.*

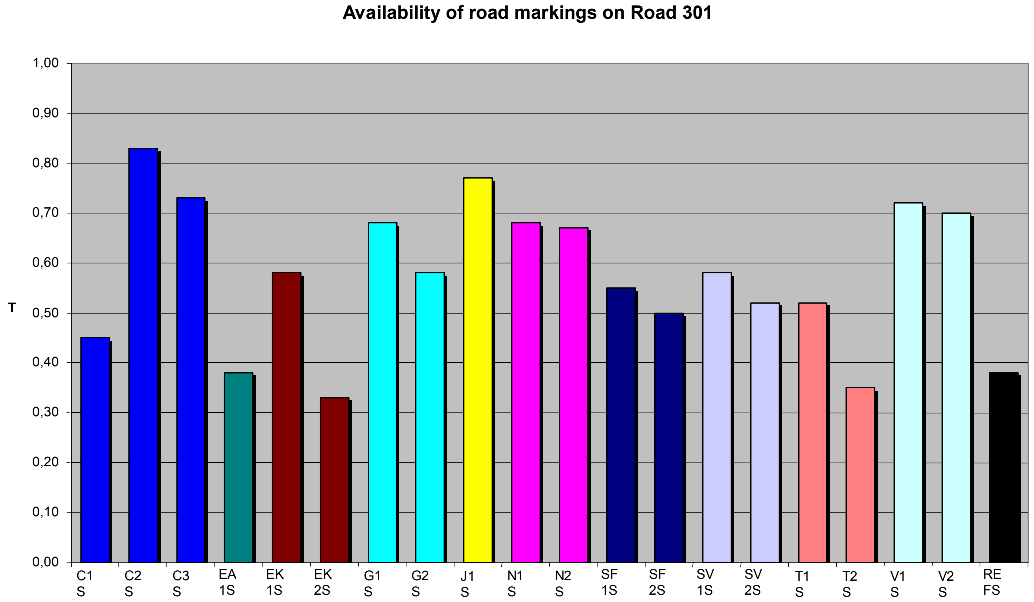

Figure 21 *Availability during winters 1998/1999 and 1999/2000 on Road 301.*

Figures 20 and 21 show that the availability of the reference markings was lower than that of most test markings. On Road 63, the best test marking had about twice the availability of the flat reference marking. On Road 301, the corresponding difference was even greater.

Generally speaking, availability on Road 63 in Värmland was greater than on Road 301 in Dalarna. This is partly due to the climate, and partly to the fact that the surface dressing on Road 301 had a very coarse texture, and with many road markings difficulty was experienced in covering the surface.

The results of winter measurements show the usefulness of corrugated wet visibility road markings: While a conventional flat edge marking seldom has acceptable visibility in the winter, the best wet visibility test markings had an availability of 0.6 – 0.8, i.e. they had an acceptable performance during roughly 60 – 80% of the time.

It must be borne in mind that the above results apply for continuous edge markings and specifically for these two winters. Care should be taken in generalising these results to other types of markings (e.g. intermittent edge lines) or other climatic conditions.

6.3 Comments on the winter measurements

If availability according to Figs. 20 and 21 is compared with the results of the comprehensive measurement, it is found that agreement is fairly good. The types of road markings which had a high availability also had a high retroreflectance value during the four comprehensive performance measurements.

7 Discussion

The results of measurements in this project are surprisingly good. The manufacturers were able to demonstrate that it is possible to produce and apply road markings that have good visibility under most weather conditions, even when the road markings are wet.

If the comprehensive performance measurements of retroreflection in the dry and wet states, luminance coefficient, coefficient of friction and wear, are studied, the findings are as follows.

On **Road 63** most test markings satisfy the requirement concerning retroreflection by a dry marking, luminance coefficient, coefficient of friction and wear, even after two winters. On the other hand, with many markings it is found difficult to satisfy the wet visibility requirement of 35 mcd/m^2/lux; after two winters, only 8 out of 19 markings meet this requirement. However, this must not be regarded as a bad result. The very fact that there are some markings which do meet this requirement after two winter – without reconditioning – shows that the manufacturers had a fair degree of success in producing wet visibility road markings. In addition, some of the markings which passed the test had values in the wet state which were far greater than those required.

It should be noted that the eight test markings which satisfied the requirement concerning wet visibility also satisfied the other performance requirements, i.e. they would have passed a complete performance test. However, none of these materials passed the laboratory test (according to the proposed revision of ATB VÄG). Six of the materials failed the indentation value test and two the test for reflectance after ageing. The last of these is remarkable: Reflectance and the luminance coefficient have a high degree of relationship – in actual fact, they are two different quantities which both describe the whiteness of the road marking. In spite of the fact that the laboratory tests failed two materials with respect to whiteness after ageing, the performance test in the field passed the same materials after two years' ageing. This is a clear indication of the poor validity of the laboratory test.

As mentioned before, the results on **Road 301** in Dalarna were much worse than in Värmland. Not one of the test markings passed a performance test after two years. One probable explanation is that the surface dressing on this road has a very coarse texture, and difficulties were therefore experienced with many materials in achieving good coverage. This was manifested by the difficulty in meeting the requirement concerning the luminance coefficient. Of the 18 test markings, only three met this requirement after two years. The requirement concerning retroreflection in the wet was satisfied by four test markings. However, none of these passed the laboratory test.

On **Road 63,** the results of retroreflection measurements in the winter are also good. During the two winters when the measurements were made, most test markings had an acceptable performance on more than 50% of the measurement occasions. Some markings even had an availability of over 70%. This is an indication that road markings have an important function to perform during the winter; they are not always covered by snow and ice during this time.

On **Road 301**, the results are again somewhat worse. The performance of almost all the test markings was unsatisfactory on more than 50% of the measurement occasions. Some had an availability of less than 10%. The probable explanation is that the performance of the road markings was worse on the coarse surface dressing, and the somewhat harsher winter climate in Dalarna may also have contributed.

One important issue is whether the results can be generalised. It must be borne in mind that the tets markings were applied as continuous lines near the road edge. This meant that they were exposed to minimum wear by traffic. If they had been laid as intermittent edge markings on a 13 m wide road (with wide shoulders), the results would probably have been different (worse). The same applies if they had been laid in a test lane over the entire carriageway; in such a case, wear due to traffic would have been considerably greater than when laid as continuous edge markings. It is probable that the results can be safely generalised so as to apply to continuous edge markings on motorways, but it is unlikely that this can be done with respect to intermittent edge markings or centre lines.

As regards the results of winter measurements, these are also very difficult to generalise. Each winter is unique, and performance might have been considerably worse during a winter with more snow and frost – the winters when the measurements were made must be regarded mild. It may also be risky to compare the different test markings with one another, since they are laid along a road. This implies that, at least on some occasions, a test marking along a section in a forest might have been exposed to less favourable conditions. The winter measurements must therefore be interpreted with great care; it is seen, however, that it is possible to achieve good performance at least during mild winters.

Another important question is whether it is realistic to lay test markings on a large scale. It is open to doubt whether they can be applied in a cost effective way, and it is also important for the components in the materials to be available at a reasonable price, so that the final product is price competitive.

In applying the test markings, fairly primitive methods were employed in some cases; it should be decidedly impossible to use these methods in normal production. However, there is nothing to prevent the development of machinery that lays even e.g. two-coat materials efficiently. Also (according to hearsay) some materials were expensive, but it is possible that the price structure will be quite different when these are bought in large quantities.

8 Conclusions

This study has shown that it is possible to produce road markings that have good visibility even in rainy weather. Several of the products have such high retroreflectance values in the wet that they have good visibility even when applied as narrow intermittent edge lines. However, if the desired pre-view time is to be achieved, the road markings must have a larger area, for instance by making the lines continuous and/or wider.

The results further show that several test markings also have a good performance during the winter months. It was far more common for them to have good visibility even in winter than to be invisible because of snow and ice. This result must not be generalised to apply to the northern parts of Sweden, nor does it apply to all test markings.

The results of this report apply to a two-year period and relate to continuous edge lines on two lane roads with carriageway widths less than 9 m. The results must not be generalised to apply to intermittent edge markings on wider roads.

9 References

Edwards, Y & Åström, S: **Fält- och laboratoriestudie av vattenburen färg. Laboratorie- studie.** (Field and laboratory study of waterborne paints. Laboratory study. In Swedish). VTI notat 31-1999. Swedish Road and Transport Research Institute, Linköping. 1999.

Isacsson, U & Colldin, Y: **Vägmarkeringsfärg. Laboratorieundersökningar och preliminära metodbeskrivningar.** (Road marking paints. Laboratory investigations and preliminary method specifications. In Swedish). VTI meddelande 343. Swedish Road and Transport Research Institute, Linköping. 1983.

Vägverket: **Val av mätplatser vid funktionskontroll av vägmarkering.** (Selection of measurement sites for performance measurement of road markings. In Swedish). Method specifications 599:1999. Swedish Road Administration, Borlänge. 1999.

Åström, H: **Utvärdering av PFT som friktionsmätare för vägmarkeringsytor.** (Evaluation of PFT as friction meter for road marking surfaces. In Swedish). VTI notat 45-2000. Swedish Road and Transport Research Institute, Linköping. 2000.