RECOMMENDATION HANDBOOK

RAINVISION

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1. INTRODUCTION

1.1. EXECUTIVE SUMMARY

The present deliverable is the RAINVISION Recommendation Handbook, work package 5 of the project.
It represents the final work of the Rainvision Project and aims to inform the reader about the results and research findings of the project. Guidelines have been developped to provide the scientific background for specifiers and regulators to choose from the available performance classes in the European Norm EN 1436.

COST 331, which ran from 1996 to 1999, mainly focused on dry night conditions and indicated that the increased luminance of road markings, resulting in a better delineation of the road, contributes to an increased comfort by offering more reaction time to the drivers. RAINVISION continues where COST 331 stopped and studies the influence of road markings on driver behaviour during wet night condition. Special attention has been given to effects and visibility needs for elderly drivers.

The guidelines also take into account the general visibility performance for both daytime and nighttime driving referring to the 'state of the art' in pavement marking design. For white road markings, Q_d classes of Q3 or Q4 are appropriate. Results of WP4 indicate that renewed pavement markings offering improved daytime visibility at the Q_d performance class Q4 did not lead to higher vehicle speeds. A pavement marking width of 15 cm for the outer urban or rural roads can be considered the state of the art.

For the nighttime visibility in dry condition it is recommended to introduce a minimum maintained performance level of the coefficient of retroreflected luminance R_L of Class R3 (minimum 150 mcd/m² lx) in for pavement markings in use.

For the nighttime visibility in wet and rainy condition it is recommended to introduce a minimum maintained performance level of the coefficient of retroreflected luminance R_L of Class RR2 (minimum 35 mcd/m² lx) for pavement markings in use. Alternatively R_L during the condition of wetness of Class RW3 (minimum 50 mcd/m² lx) should be applied. The conclusion of the WP 4 Road trial experiment was that the improved road markings do not lead to higher speeds. This is important to note, as the speed effect on the test track was not observed in real traffic.

1.2. PURPOSE

The present deliverable is the RAINVISION Recommendation Handbook, work package 5 of the project. It represents the final work of the Rainvision Project and aims to inform the reader about the results and research findings of the project. Based on this, clear guidelines have been developped for the design and performance of pavement marking based on drivers needs. Those guidelines should provide the scientific background for specifiers and regulators to choose from the available performance classes in the European Norm EN 1436.

The focus of the Rainvision project is on wet-reflectivity performance, relevant for nighttime driving in wet or rainy conditions. The guidelines also take into account the general visibility performance for both daytime and nighttime driving referring to the 'state of the art' in pavement marking design.

The RAINVISION research has been performed in 4 steps. Work Package 1 aimed to summarize the 'state of the art', following a literature study.

Work Package 2 consisted of a simulation study using driver simulation.

WP 3 was done in real driving on a closed specially prepared test track in Austria using 3 different levels of road marking performance and 3 levels of environmental condition from dry over wet to continuous rain.

WP4 was the on-road test, done in the UK for a period of more than one year on open public roads in selected sections of the road network identified as high accident sites.

The conclusions of this recommendation handbook will be made available to road authorities and stakeholders involved in road safety as part of the WP 6 for dissemination.

In chapter 2 of this recommendation handbook, an executive summary for the work packages 2, 3 and 4 is given.

1.3. SCOPE

This deliverable has been issued in the framework of the RAINVISION project under the Grant Agreement MOVE/C4/SUB/2010-125/SI2.596617/RAINVISION with the DG MOVE of the European Commission.

1.4. REFERENCES

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2. REVIEW OF RESEARCH

2.1. WP 2 SIMULATION

The purpose of this study was to assess the impact of the visibility of different road markings in night time driving during rainy conditions, also taking into account different age groups based on a driving simulator study.

An experiment was carried out on a specifically prepared driving simulator through several driving sessions in the area of Paris, France. 123 subjects were recruited based on three age groups. Prior to the simulator drive, visual performance testing was been conducted by the participants to ensure a valid interpretation of results.

Simulation test drives were carried out by simulating dark or nighttime environment within two different road delineation conditions (standard road markings and night rain visible road marking that have enhanced visibility properties during rain) on a realistic scenario of a two-lane rural road. With the help of data recorders, driving performance was measured by means of lateral position behaviour (number of errors expressed as driving lane departures and road departures).

The conclusion from the Cost 331 project was to provide road marking visibility to allow preview time of a minimum of 1,8 seconds. It was also said that 'some margin should be added for real driving to allow for more comfortable driving and for other tasks, such as looking in the rear view mirror and at instruments'. Therefore, a preview time of 2.0 seconds has been chosen as centerline. In the experiments two discrete levels of preview time at 2.5 and 1.5 seconds have been finally selected.

Enhanced visible road markings are simulated on the visual base of the simulator with a preview time of 2.5 sec, compared to standard road markings with a preview time of 1.5 sec. Preview time was calculated for the speed limit applicable in rainy conditions (i.e. 80 km/h), which is similar to the design speed of the road (posted sign speed 90 km/h).

Based on the empirically established visibility (expressed in preview time), the relating retro reflectivity can be estimated by calculation with the 'VISIBILITY programme' (developed on behalf of the COST 331 Management Committee).

Estimation of the pavement marking rain retro reflectivity based on the choosen preview time for the continuous edge line on the right side:
Enhanced Road Marking: Preview time 2.5 sec.; R_L 50 mcd/m²/lx (RR 3).
Standard Road Marking: Preview Time 1.5 sec.; R_L 15 mcd/m²/lx (RR 0).

Based on the qualitative report of the operators who monitored the driving sessions, subjects generally experienced difficulties in choosing the appropriate speed in both conditions of enhanced and standard road marking visibility.

Unfortunately, driving behaviour expressed in terms of travel time, mean lateral and longitudinal accelerations was finally not investigated, as a result of limitations of the simulator equipment and due to sources of uncertainty in the identification of the driver's sessions.

Due to unexpected difficulties, two sets of visual environment were embedded in the driving simulator. A first environment simulation (called environment simulation 1) was tested on the basis of an advanced imaging technology. Despite its intrinsic superiority, this simulation did not perform adequately: vertical objects appeared as back lighted in the road scene of the driving simulator. These abnormalities forced us to test a second visual simulation with a normal restitution of the vertical objects (called environment simulation 2).

In environment simulation 1, more visible road markings did not improve the situation compared to less visible ones, but the interpretation of results was probably biased by the unexpected presence of visual distractors. In a normal environment simulation (environment simulation 2), results indicate that road trajectory was best with visible, enhanced markings compared to less visible, standard road markings. Based on the analysis of the lateral position of the vehicle, it has been noticed that enhanced road markings may have a positive effect on the trajectory of drivers in adverse driving conditions simulated in this study. Less run-off-the road incidents and lane departures were observed with enhanced road markings compared to standard road markings. Under nighttime und rain driving conditions, the enhanced road markings may generally have guided the subjects on the driving path better than standard road markings.

From a traffic safety perspective, the use of more visible road markings in a realistic driving environment (environment simulation 2) may lead to a decrease in errors made by drivers (departures on the opposite lane, run-off the road), especially among the age groups of young and old drivers.

2.2. WP 3 TRACK SIMULATION

The purpose of this study was to scientifically assess the impact of the visibility of different pavement markings in different conditions (night time driving in dry, wet and wet & rainy circumstances), taking into account three age groups.

A field experiment was carried out on a specifically prepared test track near the city of Melk, located in federal state of Lower Austria in Austria. 90 out of a group of 120 test subjects have been selected based on psychological pre-testing to ensure a homogenous test sample for three age groups.

Test drives were carried out with three different pavement marking conditions during three nights under dry, wet and wet & rainy driving conditions with four identical test vehicles. With the help of in-vehicle data loggers, driving performance was measured by means of speed, cornering and acceleration behavior. Additionally, a questionnaire was used to measure driver's subjective comfort levels after each test run.

For the track simulation, all pavement markings have been applied in white color according to EN 1436 with a width of 12 cm. This is the standard for secondary roads in Austria which makes it the typical condition for the test subjects and the driving environment on the test track in Melk.

The following three conditions of pavement marking have been examined:

1.) Baseline condition (non-reflective)
2.) Marking material I (type 1, only dry-reflective)
3.) Marking material II (type 2, wet-reflective)

For the baseline condition non-reflective priming material has been applied, which can be hardly perceived at night, especially in dark and/or rainy weather circumstances.

As marking material I, "3M Stamark A 650" (type 1) without additional wet reflectivity feature was used. This product is a flat white pavement marking product using standard glass bead technology for night time visibility and corundum skid particles for anti slip performance on wet surfaces. This is a typical product construction used with different marking systems as thermoplastics, paint, or plastics. This product construction does not provide additional wet reflectivity performance. When the road surface is wet or covered with water, the optical system is affected and the visibility performance of the marking drops significantly.

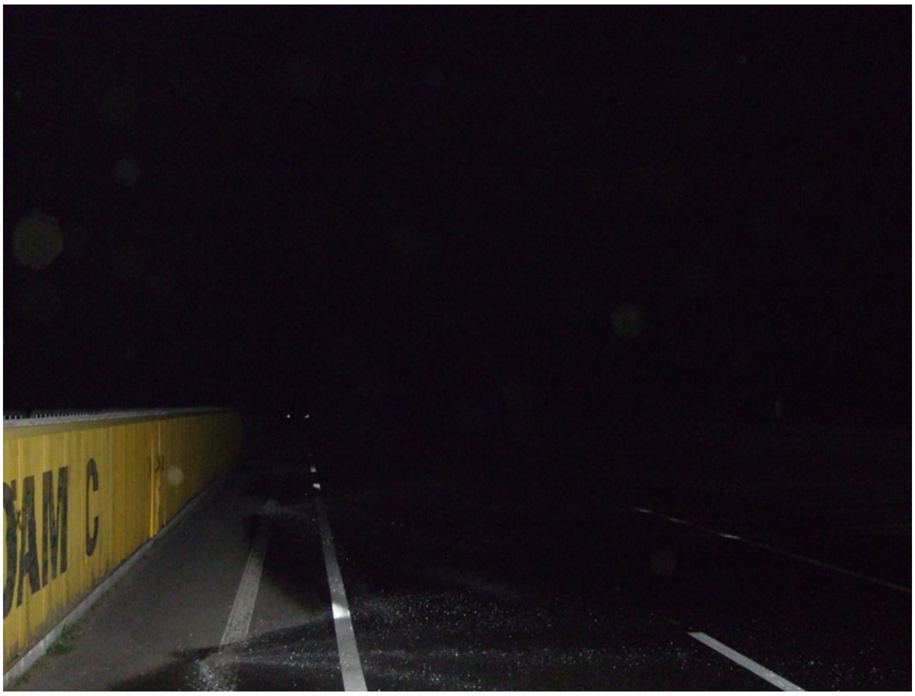

Figure 1. Marking material I, without additional wet reflectivity (picture shows wet track)

This effect is illustrated in

Figure 1 where a big difference between wet and the (triangle-shaped) dry parts of the marking material reflects the flashlight of the camera differently.

Retro-reflective parameters of “3M Stamark A 650” were measured on the track:

R_L (dry) 570 - 685mcd/m² lx (exceeding Class R5 in EN 1436)

R_L (rain) 3 -12mcd/m² lx (RR0 = no wet or rain reflectivity performance according to EN 1436)

Marking material II was “3M Stamark A 380 ESD” (type 2) with additional wet reflectivity feature. This product is a profiled white pavement marking product using ceramic glass bead technology for night time visibility and ceramic skid particles for anti slip on wet surfaces.

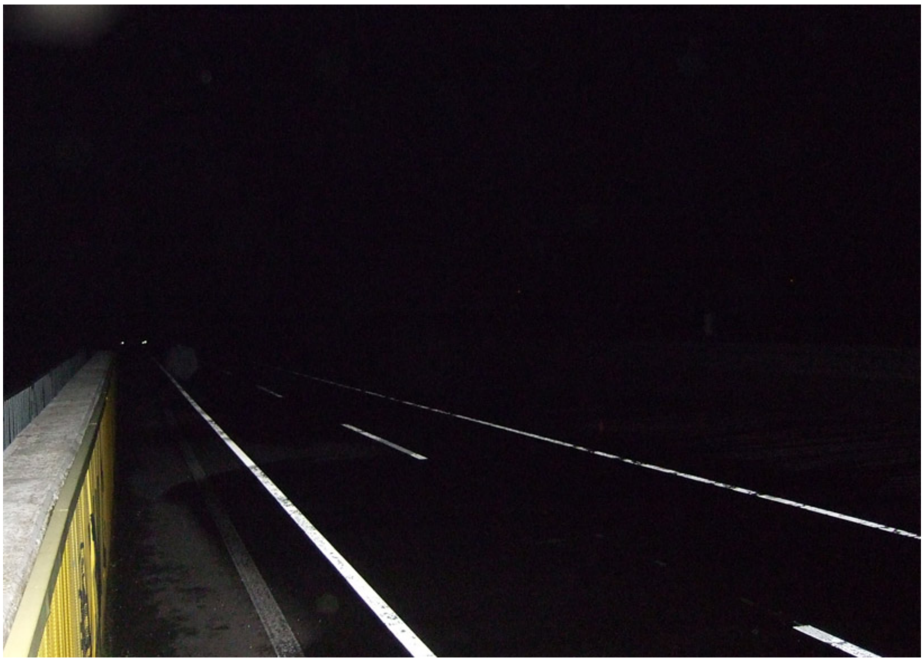

Figure 2. Marking material II, with additional wet reflectivity (picture shows wet track)

Due to the pattern profile, the material has “raised” and “drain" areas. When material becomes wet, water can rinse off the raised areas and the optical system will be exposed over the water line. Therefore, this product construction provides additional wet reflective features.

The retro-reflective characteristics of 3M Stamark A 380 ESD were measured on the track:
R_L (dry) 407 - 572mcd/m² lx (exceeding Class R5 in EN 1436)
R_L (rain) 43 - 112mcd/m² lx (Class RR2 – RR4 in wet reflectivity performance according to EN 1436, the performance range was measured in different locations and is a result of the varying rain and drainage conditions throughout the track)

Results indicate that that driving comfort as well as clearness and perceivableness of track trajectory was assessed best when marking material II (wet reflective) was applied on the track. Regarding driving behavior by means of speed choice, test subjects drove slowest in the non-reflective condition, faster under condition with applied standard dry-reflective marking material, and even slightly faster under the condition with advanced wet-reflective material. The driving behavior expressed in terms of mean lateral and longitudinal accelerations, showed no statistically significant differences after controlling for speed.

It could be clearly shown that both reflective marking materials are perceived more comfortable and guiding compared to the non-reflective marking. Applying reflective marking material has a positive effect on the subjective feeling of safety of drivers, especially in adverse driving conditions which were simulated in this experiment. Under night-time und rainy driving conditions, the wet retro-reflective material was assessed as clearly guiding the driving path, thus providing anticipatory stimuli of road environment and taking workload off the driver.

From a traffic safety perspective, the main difference in terms of traffic safety lies in the question whether to apply or not to apply reflective marking material at all. If reflective material is applied, the better choice is to use wet-reflective material instead of dry-reflective material as the benefits (subjective driver comfort and better anticipation of road trajectory) outweigh the disadvantages (slightly higher speed choice) for drivers.

2.3. WP 4 ROAD TRIALS

Work Package 4 of the Rainvision research was led by UK Road Safety Markings Association RSMA, working in liaison with highways and enforcement authorities, to identify suitable road locations. Sections of roads incorporating junctions and bends have been prioritized across two highway authority areas to find a total of 10 assessment locations in order to provide a robust statistical base for analysis.

Baseline speed data was collected with the existing pavement marking that was typically worn in all 10 locations having very limited retained retro-reflectivity and probably no wet-reflective performance.

The pavement marking was renewed with wet-reflective performance (see stage 2). Accident and driver speed data have then be collected over a full climatic cycle. Detailed analysis is undertaken in order to evaluate the impact of the on accident levels and driver behaviour in terms of speeding (see stage 3).

In detail, WP4 involved the following four stages of implementation:

STAGE 1 SITE IDENTIFICATION AND INITIAL DATA COLLECTION

Identification of high risk sites suitable for application of enhanced wet-reflective pavement markings

Table 1: Site description overview

Site No.	Speed limit [mph]	Road type	Location type
1	60	Straight	Rural
2	30	Semi-straight	Urban
3	30	Straight	Urban
4	60	Straight	Semi-urban
5	30	Slight bend	Urban
6	60	Semi-straight	Semi-urban
7	60	Straight	Semi-rural
8	60	Straight	Semi-rural
9	30	Slight bend	Urban
10	60	Slight bend	Semi-rural

Having identified the locations of the assessment points, Durham Council installed and monitored the driver behaviour at all 10 sites for a four week period between June 25th and July 23rd, 2012. The method of assessment of driver behaviour was through vehicle speed measurement using a pneumatic tube monitor. This established the baseline condition.

STAGE 2 ON ROAD TEST

During August and September of 2012 a RSMA contracting member installed the enhanced wet-reflective pavement marking on all 10 sites. The longitudinal lines on the sites were installed with the 'Line 'n' Dot' road marking system. The material used was a thermoplastic road marking material consisting of a mixture of aggregate, pigment, extender, synthetic resins, mineral oil and glass beads blended and supplied in granular form under the brand name 'EM 230 Wetlite'.

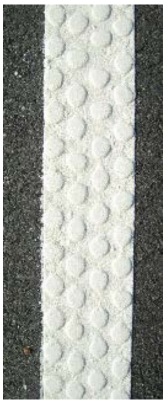

Figure 3: Enhanced wet-reflective pavement markings

It is designed for producing structured markings via extruder application, in order to achieve the enhanced wet-reflective properties.

Due to the 'Line 'n' Dot' pattern, the material has "raised" and "drain" areas. When material becomes wet, water can rinse off the raised areas and the optical system will be exposed over the water line. Therefore, this product construction provides additional wet-reflective features.

The typical retro-reflective characteristics of the installed EM 230 Wetlite system during the on-road test can be estimated from respective certification and durability testing against EN 1436:

Q_d Class Q4, exceeding 160 mcd/m² lx

R_L (dry) Class R4, exceeding 200 mcd/m² lx

R_L (wet) Class RW4, exceeding 75 mcd/m² lx

Table 2: Summary of installed pavement marking in each site

Site No.	Location	Marking width	Marking length
1	B6313 Craghead	10 cm	576m
2	A691/A6076 Lanchester	10 cm	350m
		15 cm	408m
3	B1320 Yoden Way, Peterlee	10 cm	472m
		15 cm	336m
4	A1086 Coast Road, Blackhall	10 cm	1868m
5	B1280 Wingate	10 cm	336m
6	A167 North of Cock o´ The North	10 cm	236m
7	A689 High Grange	10 cm	1536m
8	A181 Wheatley Hill	15 cm	4008m
9	C145 Essington Way	10 cm	336m
10	B6291 Coxhoe to Quarrington Hill	10 cm	2998m

After pavement marking installation, the discrete monitoring of driver speed on each site over the duration of the climatic cycle was done through 8 mobile cameras circulating through the 10 sites.
Data generation was finalized with the collation of accident statistics for the period of two climatic cycles.

STAGE 3 DETAILED STATISTICAL ANALYSIS OF SPEED AND ACCIDENT DATA

Durham County Council have recorded and compiled all accident reports for the specific sites included in the survey. Additionally, Durham Police Incident Causation reports have been investigated. These reports are, solely and necessarily, restricted to those incidents where police involvement and / or a police report has been made as a result of one or more vehicles being involved in an incident. The incident reports have been categorized into two time periods Jan 2012 – Dec 2012 and Jan 2013 – Dec 2013.

These reports have been analysed and, in the absence of a detailed extensive report, a best estimate determination as to the possible underlying cause of the incident has been made, also according to the attending police officer filling out the most likely contributing accident causation factor(s) according to accident causation grid codes.

Authors carried out an in-depth analysis of police reported accidents and assessed the potential link between incidents and possible pavement marking causation effects. This analysis concluded that none of the accidents occurred as a direct result of missing, obscured or inadequate markings or perception of the same.

Speed Analysis for Rural Sites

Average speeds slightly higher on rural roads during summer months.

Speeds drop significantly leading into early morning commuting times and rise slightly during evening commuting times remaining at a constant thereafter.

Speed Analysis for Urban Sites

Average speeds higher during pre survey monitoring (June 2012) then slightly lower after the installation of enhanced pavement marking.

All Sites Daytime Visibility

It was noted from draft analysis that the speeds of vehicles across most observed sites during hours of daytime were affected by the installation of the enhanced marking material. One of the improvements in the materials used was that of increased daytime luminance, measured as luminance factor $\beta > 0.50$ (or luminance coefficient under diffuse illumination $Q_d > 160$ mcd/m² lx). This would have a noticeable affect during daylight hours by increasing the contrast between the white markings against the carriageway background.

Street Lighting

Street lighting was observed to be installed at three out of the ten sites. There has been no notable trends regarding the lack of illumination of markings during the survey period compared with those which possess lighting columns. In order to better determine the effects, if any, of presence of lighting on vehicle behaviour we would advise that further studies of larger groups of sites, both lit and unlit, be undertaken.

ALL Sites – Year on Year comparison

The comparison of data was undertaken for June 2012 vs June 2013 and also for Dec 2012 vs Dec 2013. Whilst it was understood that the comparison of June to June was the only method undertaken with which to analyse the effect of installation this was purposely done so as ensure that the installation of markings was the major contributing factor. Analysis of Dec 2012 vs Dec 2013 was undertaken in order to assess the performance of the new markings over a climatic cycle. Meteorological data for the investigation area has been researched and assessed. It has been determined that for the comparison periods of the investigation the reports identify a number of variations in comparable periods of the climatic cycle. Most notably the winter periods Dec 2012 / Jan 2013 vs Dec 2013 was noted to have a much colder period involving much rural snow cover, therefore significantly restricting road surface visibility and presumably also affecting vehicle behaviour.

STAGE 4 CONCLUSIONS

It has been shown by analysis of the vehicle speed data collected that there are significant patterns relating to vehicle speeds throughout the day, increasing and decreasing around the morning and afternoon travel times. When all sites are taken into account the average speed decrease after installation of enhanced wet-reflective markings is 2.0mph (summer'12 to summer'13). A speed increase was noted of approximately 0.75mph to 3.75mph for the observation periods winter '12/'13 to winter '13/'14. However, it should be considered that this comparison is a consequence of weather conditions rather than potential for deterioration of markings. Moreover, it should also be noted that site 1 and site 7, being the most rural of the locations, experienced the greatest weather variation between the two winter recordings and as such an elevation in average speeds of 5.0mph and 5.2mph, respectively, was not considered solely resultant from the markings alterations.

Generally, speed differences between the sites, although small in absolute terms, tend to suggest that there have been decreases in speed between the start and finish dates of the test period. Although only a small data set of accidents is available for the investigation period, it appears that accident causes were not directly associated with performance limitations of road markings.

To summarise, results indicate that enhanced wet-reflective pavement markings do not lead to higher vehicle speeds. On the contrary, speed decreases of about 2mph on average across all sites were observed when controlled for weather conditions. In terms of road safety, results can be interpreted as being promising at least, according to Taylor et al. (7, 8), as changes in driving speed alters accident numbers. Based on this relationship, it is more than fair to conclude that decreased speed is linked with lower accident risk - amongst other accident influencing, extenuating factors, such as weather, complexity of road layout, traffic density, etc.

In order to determine a more robust deduction, i.e. the extent of this relationship, it is considered necessary to extend the survey to a larger area, for a longer duration as well as using a single monitoring methodology. This approach would allow for reducing unwanted biasing factors, such as variations in weather, climate, apparatus and traffic.

3. RECOMMENDATION HANDBOOK

3.1. FOREWORD

The idea of the RAINVISION 'Recommendation Handbook' is to supply clear guidelines for the wet reflective performance of retroreflective road markings based on drivers needs. Those guidelines should provide the scientific background for specifiers and regulators to choose from the available performance classes in the European Norm EN 1436.

COST 331, which ran from 1996 to 1999, mainly focused on dry night conditions and indicated that the increased luminance of road markings, resulting in a better delineation of the road, contributes to an increased comfort by offering more reaction time to the drivers. On average a slight increase in speed was noted, but the increased visibility was mainly converted into more reaction time (1).

IMPROVER, which ran from 2004 to 2006, concluded that road markings are a key factor to achieve safe road infrastructure. Nevertheless, road markings are generally neglected and, in many cases, have even completely disappeared. Several recommendations were provided for high accident areas and the project confirmed the need for 'wet-night visibility' (9).

RAINVISION continues where COST 331 stopped and studies the influence of road markings on night time driver behaviour. Special attention has been given to effects and visibility needs for elderly drivers. According to the European Road Safety Action Programme, older drivers were responsible for 20% of accident. With the aging society in Europe, and the changing lifestyle of active seniors, even more elderly drivers are expected in the future. This is why the research in WP 2 and WP 3 was undertaken for 3 different age groups. Some of the following aspects have been studied:

- Does better visibility of pavement markings during wet and rainy nights contribute to better driving comfort and road safety?
- How does the impact of increased visibility vary according to age?
- Other things being equal, do men and women show different reactions?
- What levels of wet-reflectivity are adequate to meet drivers needs

The road markings for RAINVISION experiments, both simulated and real, have been classified according to the European Norm EN 1436 'Road marking materials — Road marking performance for road users'. This norm defines the various performance classes, levels and test methods for 'Dry', 'Wet' and 'Rain' night time retro-reflectivity as well as colour and daytime luminance. The experiments have been limited to white pavement marking.

The RAINVISION research has been performed in 3 steps.
Work Package 2 consisted of a simulation study using driver simulation.

WP 3 was done in real driving on a closed specially prepared test track in Austria, while WP4 was the on-road test, done in the UK during more than one year on open traffic on prepared section on high accident sites.
The conclusions of this recommendations handbook will be made available to road authorities and stakeholders involved in road safety as part of the WP 6 for dissemination.

3.2. PAVEMENT MARKING TECHNOLOGY

Pavement markings are designed to meet the product characteristics described in the european norm EN 1436 'Road Marking Materials - Performance for Road Users'. The standard is intended as performance specification which concentrates on the needs of the drivers. The standard specifies the performance for the road user of white and yellow road markings based on the following product characteristics:

1.) luminance and colour for the day-time visibility
2.) Retroreflection in dry, wet and rainy condition for the night-time visibility
3.) skid resistance to ensure some balance in tire grip between the marking and the surrounding road surface

Those product characteristics are typically tested for durability and should be interpreted as 'in-use' requirements or maintenance levels for installed road markings.

Higgins et al. (3) elaborate about pavement marking constructions and the performance effects for wet-reflectivity: Common pavement markings feature exposed glass bead optics. In most cases, the beads are dropped onto a white or yellow binder right after the binder is applied onto the roadway surface. Pavement markings attain their level of visibility in nighttime via retroreflection, where optics in the marking reflect the incident headlight illumination back toward the driver. Although most pavement markings are efficient retroreflectors in dry conditions, their efficiency can substantially diminish under continuous wetting conditions. As a result, pavement markings can seem to disappear at night in wet and rainy conditions. There are two primary reasons for the degradation in retroreflectivity under wet-weather conditions. First, during rain the accumulating water forms a continuous layer on top of the marking optics and much of the incident light that would ordinarily be retroreflected is lost due to specular reflection off the surface of this water layer. Second, this same water layer actually changes the optical efficiency of the pavement marking optics. Water on a pavement marking system using 1.5 refractive index glass beads reduces its retroreflective efficiency such that very little of the light that does penetrate through the water layer is retroreflected back to the driver. In short, pavement marking optics that perform adequately under dry conditions often suffer in retroreflective efficiency under wet conditions. Nearly every nighttime driver can attest to the challenging driving environment and increased visual demand during rain at night. Under wet or raining conditions the retroreflective efficiency of conventional pavement markings drops dramatically making it difficult for drivers to maintain position within their travel lane or choose the appropriate safe route down the road.

A common way to achieve some level of wet-reflectivity is the use of structured markings. Structured markings can have a random or regular pattern in order for the marking to have “raised” and “drain" areas. When the pavement marking becomes wet, water can rinse off the raised areas and the standard optical system will be exposed over the water line. Therefore, this product construction provides additional wet-reflective features. The same effect can also be achieved by using very large optical (bead) elements that are not fully drained during conditions of wetness. As long as the optics in the pavement marking are not fully covered with water, some level of improved wet-reflectivity is achieved. Under heavy rain condition, the structured markings are typically drowned and will loose their reflectivity. Therefore, structured markings typically have a significant performance difference for the R_L measured during condition of wetness (RW) and the continuous rain method (RR). This is also illustrated in research by Carlson et al. (4).

During the Rainvision experiments, structured markings have been used in WP 3 (track test) and WP 4 (road trials).

Another concept to achieve ‘under water’ reflectivity is the additional use of optics with high refractive indices. This will provide retroreflectivity performance during continuous rain condition, even when the pavement marking is fully covered with water.

The retroreflective performance of a pavement marking with exposed beads heavily depends on the refractive index of the glass beads. Most conventional paint and bead markings incorporate glass beads with a refractive index of 1.5. Optimal bead refractive index in dry conditions is about 1.9, at which point the beads retroreflect the highest percentage of incident headlight back to the driver. Yet to provide retroreflective properties under water, the refractive index must be considerably higher. The optimal bead refractive index to allow retroreflection under a layer of water is approximately 2.5. While today there is no technology that can produce sufficiently durable beads at such a high refractive index, beads with a refractive index of 2.4 are commercially available. Beads with a refractive index of 2.4 have very low retroreflective efficiency under dry conditions, but work effectively under wet conditions. Therefore, the pavement marking must combine glass beads of at least two levels of refractive index. Respective materials have been extensively tested by Higgins et al. (3) and typically exceed the highest performance for R_L during the condition of continuous rain Class RR6, exceeding 150 mcd/m² lx.

3.3. DESIGN AND PERFORMANCE OF PAVEMENT MARKING

3.3.1. DAYTIME VISIBILITY

The daytime visibility of pavement marking is a result of the contrast between the markings and the surrounding road surface.

For daytime visibility, the pavement markings are typically specified in both colour and daytime luminance performance. EN 1436 does offer two possibilities to measure the daytime luminance. First the luminance coefficient under diffuse illumination Q_d, and second the luminance factor β.

These parameters are also relevant for effective operation of Lane Departure Warning Systems 'LDWS', both active or passive. This technology typically relies on camera technology reading the contrast between the markings and the surrounding road surface. As the camera focus is fairly close to the vehicle, sometimes located in the underbody, there is less relevance of the retroreflective properties and more emphasis on the daytime parameters of the pavement marking for reliable operation of LDWS.

Following the recommendations of Cost 331, for white road markings, Q_d classes of Q3 or Q4 are appropriate. These classes are technically and economically feasible and are met with current pavement marking designs (1). While Class Q3 may be choosen for darker surfaces, such as asphaltic surfaces, Class Q4 may be needed for lighter surfaces using light stone aggregates or concrete.
If specifying performance for the luminance factor β, the corresponding performance classes would be B3 and B4.

As the focus of the Rainvision project is about the nighttime visibility of pavement marking during wetness and rain, only limited findings have been gathered for daytime visibility.
These are essentially the results of the road trials in work package 4, that evaluated speed data and accident statistics also during daytime. Results indicate that renewed pavement markings offering improved daytime visibility at the Q_d performance class Q4 did not lead to higher vehicle speeds.

3.3.2. NIGHTTIME VISIBILITY IN DRY CONDITION

The nighttime visibility of pavement marking in dry conditions is typically associated with the level of the coefficient of retroreflected luminance R_L and the projected surface or marking width.

Research from both Higgins et al. (3) and Schnell et al. (6) clearly demonstrated the correlation between the pavement marking reflectivity and the visibility distance that is often measured as 'preview time'. Increases in R_L also increase the visibility distance and resulting preview time of the

pavement marking. It is also stated that increasing the retroreflectance seems to have a more pronounced and practical effect in increasing visibility distances of pavement markings than increasing the line width (6).
Also Carlson et al. in their 2012 research (10) found ‘compelling evidence, demonstrating that maintenance of pavement markings retroreflectivity can have a positive effect on safety’. No attempt though was done to develop or validate threshold levels for retroreflectivity.

PAVEMENT MARKING REFLECTIVITY

In the ‘Guidelines for Road Marking Design’ in Cost 331 (1) a performance level for the coefficient of retroreflected luminance R_L of Class R2 (minimum 100 mcd/m² lx) was defined as adequate under ideal conditions. Ideal conditions are meant as for ‘young drivers, powerful headlamps, absence of glare’. For other than ideal conditions (e.g. higher age of the driver, less efficient headlamps and occurrence of glare) the visibility distance decreases down to about half of the distance. Such conditions are realistic, more common than ideal conditions, and will occur for most roads, at least for some drivers in some periods. In that respect, the reflectivity performance of Class R2 is only a compromise, dating back to the ‘state of the art’ in the year 1997-1999, taking into account the available technology at that time.

More recent analysis of relevant research, empirical evidence and a review of current regulations in different EU Member States from the year 2014, led to a recommendation of a minimum maintained performance level of the coefficient of retroreflected luminance R_L of Class R3 (minimum 150 mcd/m² lx) in dry condition (ERF, 2). It is also stated in the ERF report that there is a lack of enforcement of the national regulations, even in those countries that have established minimum threshold levels for the maintenance of pavement markings. The main problem is that little is done to monitor performance and to enforce maintenance standards that determine when a road marking should be replaced/maintained after its initial performance period.

Current European Directive 2008/96 on Infrastructure Safety Management stipulates a common management framework for TEN-T roads at EU level. In some countries, this has been extended to other roads as well. Hopefully, the revised infrastructure directive, expected for publication in 2015, will lead to better enforcement of the national regulations. This should adress the pavement marking visibility needs of an ageing population.

Rainvision experiments in work package 3 (track trials) have been done with new pavement markings of performance class for R_L (dry) of R5. The reflectivity performance during the on-road test in WP4 has been estimated as R_L (dry) Class R4 during the period of the test.

Increased visibility of pavement markings is often suspected to result in drivers to increase their speed. For this reason, the research on pavement marking visibility is typically challenged with the question about speed. Obviously, increased speed does not contribute to traffic safety. According to Taylor et al. (2000, 2002), changes in driving speed alters accident numbers.

Cost 331 (1) already looked at the effects of improved pavement marking on speed choice of drivers and concluded: 'The driving speed remained on average the same after application of new road markings, while visibility distances increased in most cases, from about 45 to 90 m. Accordingly, the preview time increased in those cases up to about 3s. An interpretation may be that the test subjects were able to cope with a preview time of about 2 s, but preferred a longer preview time, when made available by the new road markings. This is probably more comfortable, and may perhaps lead to prevention of some single accidents, which form the dominant type of accidents at night in rural conditions'.

During the track test done in the Rainvision work package 3, it was found that there is a speed effect with improved pavement marking visibility. Regarding driving behavior by means of speed choice, test subjects drove slowest in the non-reflective condition, faster under condition with applied standard dry-reflective marking material, and even slightly faster under the condition with advanced wet-reflective material. To some extent, the observed speed effect must be considered an artifical result, as it has been found under the closed circuit conditions of the track with only single vehicles underway. The driving behavior expressed in terms of mean lateral and longitudinal accelerations, showed no statistically significant differences after controlling for speed. However, despite the increased speed, the driving comfort as well as clearness and perceivableness of track trajectory was assessed best with high reflective pavement markings.

The conclusion of the WP 4 Road trial experiment was that the improved road markings do not lead to higher speeds. This is important to note, as the speed effect on the test track was not observed in real traffic.

It is therefore recommended to introduce a minimum maintained performance level of the coefficient of retroreflected luminance R_L of Class R3 (minimum 150 mcd/m² lx) in dry condition for pavement markings in use.

PAVEMENT MARKING WIDTH

Regarding the pavement marking width, the experiments done in the Rainvision project did respect the national regulations. For the track test in WP3, the markings width of 12 cm was choosen, corresponding to the standard for secondary roads in Austria. For the UK road trials, the pavement marking width of 10 cm for urban and 15 cm for the rural environment was applied.

According to research by Carlson et al. (5), the increased pavement marking width of 15 cm (6 inch) on all major highways (together with other safety measures) has led to a 25 percent reduction in lane departure fatalities. The research also states: 'The use of wider pavement markings continues to grow across the United States and research results are looking favorable in terms of the impact on safety'. Researchers showed that major improvements in lane keeping are associated with wider pavement markings.

Following the survey on current national policies by the ERF (2), a pavement marking width of 15 cm for the outer urban or rural roads can be considered the recommended state of the art.

3.3.3. NIGHTTIME VISIBILITY DURING CONDITION OF WETNESS AND RAIN

Wet and rainy conditions reduce the reflectivity and the visibility of pavement markings in headlamp illumination. The technical background is outlined in chapter 3.2. It will depend on the design and construction of the pavement marking, to what extend the reflectivity under wetness and rain can be retained. EN 1436 offers two options to assess the respective performance. Most common is the method for wet-reflectivity, also called 'recovery' or bucket method. Most structured markings perform well under this test, as it allows for 60 seconds of water drain before the reflectivity is measured. The wet-reflectivity method clearly favors the structured geometry. More demanding is the test for the performance under continuous rain. Due to the complexity of this test, it is not very common and only performed in a few countries in Europe.

Carlson et al. (4) did extensive research on the question of reasonable rainfall rate for the assessment of the rain-reflectivity measurement. While the wet-reflectivity 'recovery method' does favor structured markings, the performance under continuous rain is much more demanding. In EN 1436, the rainfall rate for the rain reflectivity is set as 20 mm/hr. Carlson looked at wet-reflectivity (recovery method) and continuous rainfall rates from 7 mm/hr up to completely flooding the pavement marking at a rate of 500 mm/hr and compared various pavement marking constructions. It was clearly shown that even the lowest rainfall rate of only 7 mm/hr resulted in much lower retained R_L values than the wet-reflective method. The rate of 20 mm/hr in EN 1436 represents a strong rain, but certainly not uncommon in many regions in central and northern Europe. Strong showers will exceed the rain rate, but this will typically also exceed the drainange capability of the road and drivers must reduce speed.

Accordingly, national regulations and technical specifications should aim at performance under continuous rain, rather than rely on the wet-recovery method and performance Class RW.

Alternatively, higher performance requirements should be formulated for the wet-reflectivity, in order to assure sufficient visibility under continuous rain.

According to the ERF survey (2), most national regulations only have requirements for the wet-reflectivity, commonly at the performance level of RW2 (minimum 35 mcd/m^2 lx). This does not seem adequate for the condition of continuous rain, when the retained R_L will be significantly lower.

During the simulator trials, it could be shown that young and elderly drivers benefit most from improvements in pavement marking visibility. This is important to note, as both age groups are overrepresented when it comes to traffic accidents. According to the European Road Safety Action Programme, older drivers were responsible for 20% of accident. And more elderly drivers will be on the road in the future in our aging society. More emphasis must be given to the needs of this age group.

Rainvision experiments in work package 3 (track trials) have been done with new pavement markings. Under the real continuous wetting conditions on the test track in Melk, reflectivity performance has been measured and found to vary between R_L of 43 – 112 mcd/m^2 (representing Class RR2 to RR4) for the type II marking. The performance range was measured in different locations and is a result of the varying rain and drainage conditions throughout the track. Both baseline markings and the standard (type I) marking performed only at the RW0 and RR0 level.

In the UK road trials performed in work package 4, the retro-reflective characteristics of the enhanced wet-reflective markings during the on-road test have been estimated as R_L (wet) Class RW4, exceeding 75 mcd/m^2 lx.

In order to achieve the positive effects on visibility, driving comfort and safety that have been found in Rainvision WP3 and WP4, it is therefore recommended to introduce a minimum maintained performance level of the coefficient of retroreflected luminance R_L during the condition of rain of Class RR2 (minimum 35 mcd/m^2 lx) for pavement markings in use. Alternatively R_L during the condition of wetness of Class RW3 (minimum 50 mcd/m^2 lx) should be applied.