DYNAMIC ROAD MARKING;
A TOOL TO CREATE INFRASTRUCTURE ON DEMAND

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1. Introduction

A few years ago a futuristic project was started in the Netherlands called "Roads to the future". With that project we looked for solutions for infrastructural problems which appear already now but will be more worse in the future (like congestion during rush hours). One of the ideas was to create infrastructure on demand. That means that a two-lane carriageway of a highway could for example be converted during rush hour into a carriageway with three narrower lanes, while still retaining the hard shoulder.
For that we need a system in which road marking can be adapted in line with the traffic situation in the form of different lane layouts.
The identifiability and comprehensibility of the various traffic situations that can be obtained with the aid of dynamic road marking are highly important. This has led the experts to conclude that the road marking must be strictly confined to what is in fact being used at the time. From the marking displayed it must be clear for the road user which lane layout is being used.
With respect to the best technique for dynamic road marking, private industry in Europe has been asked to come up with ideas. Eventually they came up with a system that emitted light by using fibre optic technology. This product had to be tested in a real life situation and was the source of new functional specifications which had to be written for future products. Besides the product technical approach we also looked at the drivers behaviour in relation to the product.

2. Setting up the pilot drafting

The pilot for the dynamic road marking was build on a straight section of the A 15 between Papendrecht and Wijngaarden in the Netherlands. For this pilot we did not chose for the 2 to 3 lane situation retaining the hard shoulder, but we used the hard shoulder as the 3rd lane during rush hour. The pilot was carried out from June until November 1999.

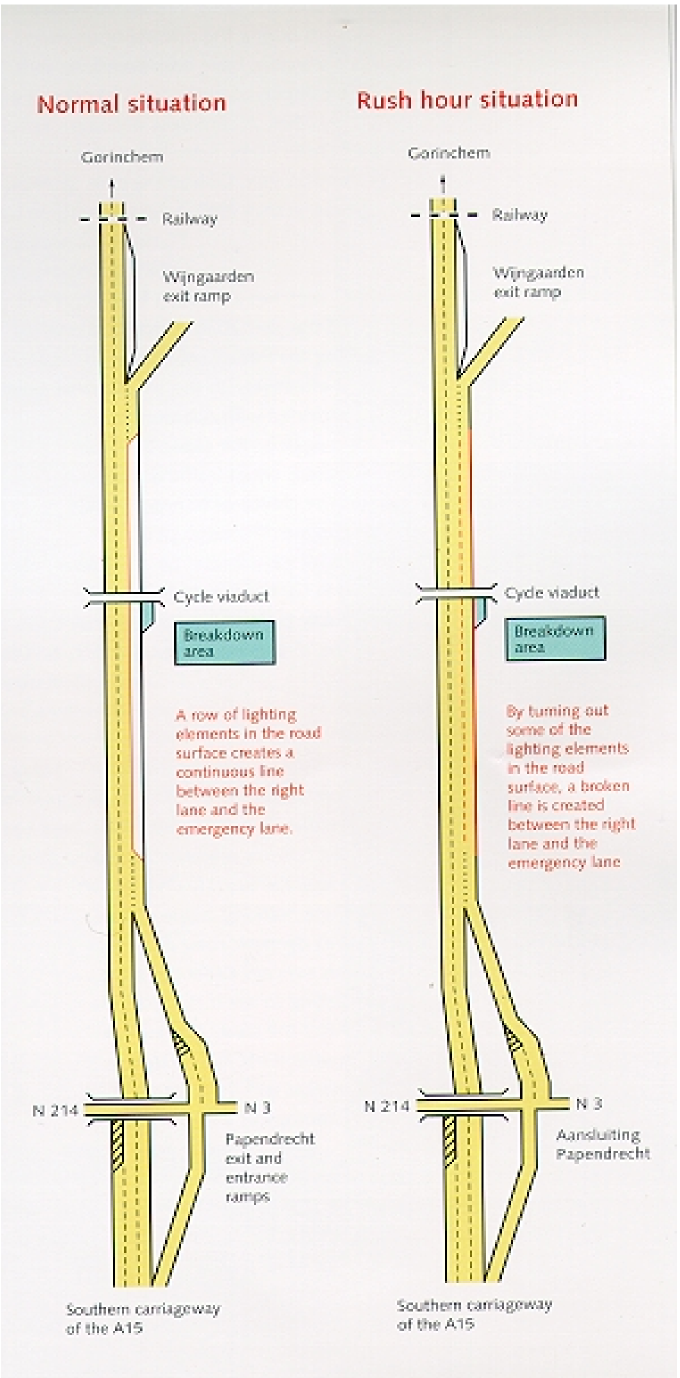

Fig. 1 Test field situation on the A 15

Therefor the site was reconstructed. A new foundation was made and a new asphalt packet was produced. A 5 cm thick porous asphalt top layer was made wherein the dynamic road marking together with all the supporting equipment was build in.

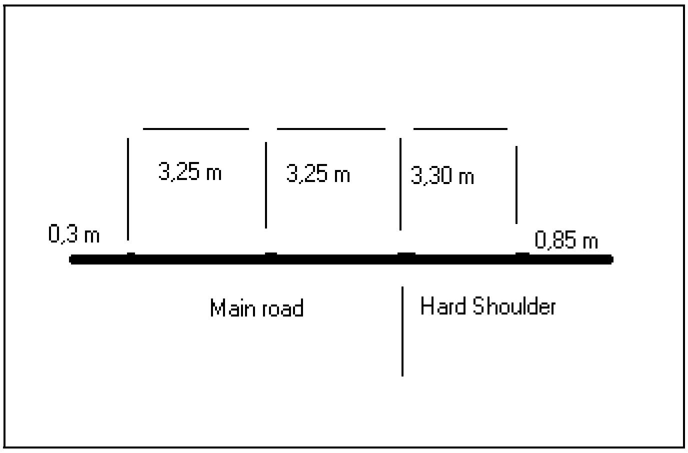

Fig. 2 cross-section of test field

The test field was approximately 1100 meters long and equipped with video detection. A break down port was situated half way the test field for emergency purpose. Stagnation was detected by the video cameras and alarmed to the operator at the traffic control centre. From this traffic control centre the dynamic road marking could be switched on and off using a special procedure.

3. Operating the system

The system is operated from a traffic control centre about 3 km away from the test field. The TV cameras produce video images on a multimedia screen in the traffic control centre and are able to detect stagnation of the traffic. The operator can see what is happening at the test field and recordings can be made on video tape. The switching schedule can be started by the operator at any moment.

In the 2 lane situation the most right edge line (on the hard shoulder) is switched out. The left dynamic line is lit continuous to appear as a right edge line. At the end of the filtering lane the edge line of this filtering lane which turns left to the right edge line of the main road is also lit. At the end of the test field the right edge line of the main road which turns right to the edge line of the deceleration lane is also lit. Both these lines are switched out when changing from the 2 lane situation to the 3 lane situation. The 3 signs above the road show the maximum speed of 90 km/h and the right edge line on the hard shoulder is switched on. After that the left dynamic line changes from continuous to broken (3-9 system). This will take a few minutes.

From this situation back to the 2 lane situation the procedure is as follows. The right sign above the road shows a left pointed arrow. The other 2 signs above the road show a green straight arrow. When all the cars have changed lanes and there is no car driving on the hard shoulder, the right sign above the road shows a red cross. The edge line (turning to the left) at the end of the filtering lane is switched on. The left dynamic line on the main road is switched to continuous mode (unbroken line) and the right edge line is switched off. The edge line at the beginning of the deceleration lane is switched on. After a few minutes the signs above the road are switched off and the 2 lane situation is restored.

When in 3 lane mode the video cameras can detect stagnation because of an accident or malfunction of a car. The operator will be warned by the system and is able to restore the 2 lane situation as described above and clear the hard shoulder for emergency traffic. This will also be the case when a vehicle is parked on the break down area.

4. Requirements of a dynamic road marking

The main requirement for this dynamic road marking was that it should be able to switch on and off in other words it must be visible in the on mode and invisible in the off mode in daylight and during the night (in darkness). Of course the specifications of conventional road markings for skid resistance, dimensions etc. were valid. The product had to be strong enough to resist the heavy traffic loads and weather conditions in the Netherlands. The product also had to be safe, especial for motor bikers.
The complete system of dynamic road marking, including the operating system with video detection and light dimming system had to be reliable.

5. Description of the product

The product for dynamic road marking, used at the pilot location on the A15 consists of an luminaire in which the so called fibre optics are situated. 4 fibres are placed next to each other forming a white area with a width of 15 cm. The luminaire was made of a polyurethane synthetic material, coloured black. The surface is profiled to meet the requirements for skid resistance (see figure 3). This luminaire was mounted on a steel carrier and constructed into the asphalt top layer (porous asphalt) and had a total depth of 6 cm. The light source was placed beside the road (for maintenance without disturbing the traffic) inside of a concrete box. The light was transported by the optical fibres from the light source to the luminaire in the road. The fibres were placed in plastic tubes which are fraised into the asphalt under layer and covered by the asphalt top layer. The light source could be dimmed by a mechanical device consisting of a wheel with different hole patterns. It was this technique which caused the colour of the light to change. The dimming device was synchronised for all light sources and worked automatically using a light detector for measuring the amount of sunlight. It was also possible to overrule this automatic dimming system manually.
The fibres are positioned so that they will emit the light in the right direction for the drivers. The angles under what the drivers are able to see the marking are very important for the interpretation of the situation (i.e. 2 or 3 lanes available).
The construction was very open to keep the water flowing through the porous asphalt and not being blocked by the road marking.

Fig 3. Luminaire of polyurethane containing optical fibres as mounted in porous asphalt

6. Measurements for functional specifications

After building the test field and before the traffic was put on the track, the skid resistance and the height of the dynamic road marking was measured. This was done by using the Skid Resistance Tester (Stanley). Because the trailing length of 126 mm could not be realised with this product, this was not a proper measuring method. Therefor a brake test with a motorbike was carried out as well. With an acceleration measurement device we were able to measure the brake delay in m/s^2. The experiments were carried out under wet conditions using a motorbike with ABS and one without ABS (see figure 4).

Fig. 4 Measurement of brake delay with motorbike without ABS

The strength of the product was tested in the laboratory before mounting in the road. The pressure sensitivity was tested using a press and the “falling ball test” was carried out .
One of the most important requirements of course is the visibility and invisibility of the dynamic road marking. Because this product differs very much from a conventional road marking made of thermoplastic or road paint and does not reflect light but emits light, we had to choose a different measurement technique. For this product we have chosen for measuring the luminance of the light which came out of the optic fibres and the light reflected by the asphalt just near the lines instead of the reflected light from the sun or the head lights of a car. With these two figures we could calculate the contrast value which is decisive for the day time visibility. This was done at several spots and driving with the traffic.

Fig. 5 Measuring the visibility with a special scientific video camera from inside a vehicle.

The light measurements were carried out using a Princeton-Instruments scientific camera equipped with a fotopical filter in order to meet the sensitivity of the human eye. This camera takes pictures with a very wide dynamic range.
Two object-glasses were used . One with a view angle of 10°, used for the luminance measurements at the viewing point of approximately 40 meters ahead and one with a view angle of 60° to reproduce the natural perspective of the road user.
The camera is calibrated with a luminance meter Minolta LS-100 with a measuring area of 1°.
The colour of the emitted light is measured with a colour luminance meter Minolta CS-100. The chromaticity co-ordinates are determined according to the CIE colour diagram. These luminance meters are both calibrated in the laboratory and they produce a measuring error of maximum 5 %.
The luminance values of both the conventional markings (thermoplastic) and the dynamic marking were measured so a good comparison of the two materials was possible.

7. Drivers behaviour in accordance to dynamic road marking

For this part of the evaluation of the pilot experiment, drivers are asked questions and video recordings are made and analysed at several times during the day. 64 % of the interviewed drivers were regular users of this road part (more then 3 times a week) and only 8 % of the interviewed drivers were first time users. The interviews were taken in September/October 1999.

The answers to the questions gave a lot of information about how the drivers experienced the pilot and how recognisable the dynamic road marking was.
48 % of the road users say that the new situation (using the hard shoulder at rush hours with the dynamic road marking) is a more safe situation than the existing one where they could use only 2 lanes. No bottle-necking effect was determined at the transition point back to 2 lanes.
84 % of the road users say that the lanes are not too narrow while 13 % say that the lanes are too narrow.

The visibility is for most drivers acceptable except in the early morning when the sun just rises in the east. The A 15 is a west - east link road so this can explain the opinion.
There is not a significant difference between the regular users and the first time users although the answers expelled that first time users have a little bit more problems of understanding the new situation.

The video recordings showed that during the time that the 2 lane situation was switched to the 3 lane situation, no problems with confused drivers occurred. Illegal use of the hard shoulder was incidentally detected during the test.
When the hard shoulder was used as the third lane, nobody used it as an emergency lane.
No problems with inserting and deflecting vehicles occurred during the experiment.
The dynamic road marking did not decrease the attention of the driver. The transition between the conventional thermoplastic marking and the new dynamic marking did not cause problems for the drivers.

8. Measurement results

Strength or durability

The product as tested on the A15 was not resistant to the heavy traffic load. The plastic cover part was seriously damaged and at some spots the construction completely went to pieces (see figure 6) within 5 months time although the laboratory tests were satisfactorily. Again the tests usually carried out on conventional thermoplastic road markings were invalid for this new product.

Fig. 6 Damaged part of dynamic road marking

Skid Resistance

The SRV (Skid Resistance Value) as measured with the Skid Resistance Tester was far to low to meet the Dutch requirements of 55 (mean value) SRV units. The mean value out of 20 measurements was 47 for the right line and 52 for the left line before exposing to the traffic load. The porous asphalt as used at the pilot test field reached the value of about 70 SRV units while the thermoplastic lines at the test location reached a value of 61 SRV units.

Using the brake delay method the dynamic marking scored a value of 2,2 until 2,7 m/s^2 without using ABS (Anti Blocking System) and a value of 4,8 until 5,3 m/s^2 with ABS. Figures for the porous asphalt under the same conditions were 4 (without ABS) and 8 m/s^2 (with ABS). The thermoplastic road marking at the test location measured 3,4 (without ABS) and 7 m/s^2 (with ABS).

Visibility

The left edge line and the left centre line are made out of thermoplastic material. The right edge line and the right centre line are formed by the dynamic road marking.
The contrast ratio depends on the view angle and is far more critical for the dynamic road marking compared to the thermoplastic.
The visibility was measured about 4 months after commissioning of the pilot experiment due to organisational problems. The luminance values of the emitted light, measured at that time, were about ten times lower than before commissioning of the experiment (measured in the laboratory). This means that ageing has in important effect on the light emission.
Nevertheless the visibility was acceptable for drivers on the right lane and the hard shoulder, but was poor for the drivers on the left lane.

Fig. 7 Night time visibility

Fig. 8 Day time visibility

The visibility during night time was comparable with the thermoplastic road marking at the test field as illustrated in fig. 7. The contrast ratio however for the dynamic marking was much higher than for the conventional thermoplastic road marking.
For the day time situation the contrast values were still higher but the difference was not so big. The contrast values were in the range of 3 to 14 with some exceptions due to a malfunctioning dimming device.

	Thermoplastic marking		Dynamic marking	
distance (m) /vertical view angle (°)	Edge line left contrast value /horiz. angle (°)	Centre line left contrast value /horiz. angle (°)	Centre line right contrast value /horiz. angle (°)	Edge line right contrast value /horiz. angle (°)
18 / 6	2,2 / 25° *	1,9 / 16° *	1,3 / 5° *	6,5 / 5° *
35 / 3	1,9 / 14° *	1,1 / 8° *	2,2 / 3° *	10,2 / 3° *
50 / 2			3,8 / 2°	28 / 2°
100/ 1	1,4 / 5°	0,8 / 3°	3,0 / 1°	8,1 / 1°
18 / 6	4,8 / 16° *	3,2 / 5° *	3,2 / 5°	10,9 / 16° *
35 / 3	2,7 / 8° *	2,9 / 3°	8,5 / 3°	14,2 / 8° *
50 / 2		2,2 / 2°	8,4 / 2°	27 / 6°
100/ 1	2,4 / 3°	1,1 / 1°	1,9 / 1°	6,8 / 3°
18 / 6	2,1 / 5° *	2,7 / 5°	3,1 / 16° *	4,6 / 25° *
35 / 3	2,7 / 3°	2,3 / 3°	8,8 / 8° *	13,7 / 14° *
50 / 2	2,6 / 2°	2,1 / 2°	3,0 / 6°	
100/ 1	1,6 / 1°	1,4 / 1°	0,8 / 3°	3,5 / 5°

Table 1. Contrast values at different view angles during day time
Measured with 10° f = 50 mm object-glass except * measured with 60° f = 8 mm object-glass.

Colour

The colour of the undimmed light matches the values for thermoplastic markings according to the CIE colour diagram. When the light was dimmed the colour was not white anymore but varied between green, white and blue. This was caused by scattering effects of the mechanical dimming device.

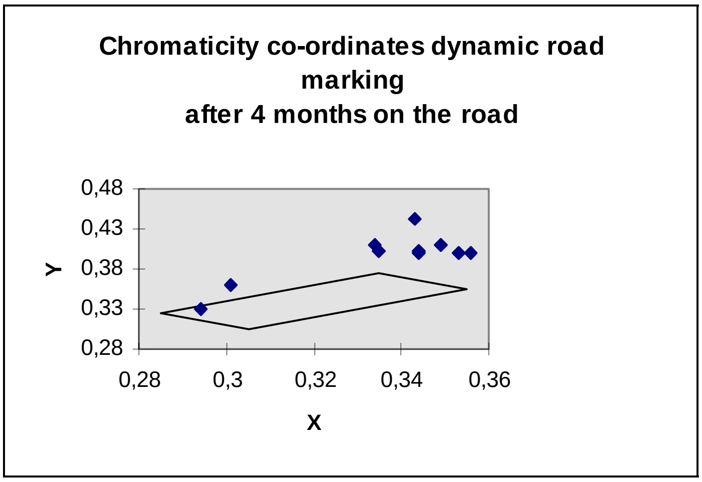

Fig. 7 Colour values. Only one point matches the requirements (undimmed light)

9. Conclusions

The dynamic road marking as tested on the A15 in The Netherlands is recognisable for the road user as a road marking and for that useful to create dynamic lane-layout.

The visibility as measured by the luminance meters and calculated to contrast values for the dynamic road marking varies with the observation angle. The marking was clearly visible when driving on the right (hard shoulder) and centre lane (in the 3 lane situation) but not very well visible when driving on the left lane.

The contrast values differ a lot in distance but are acceptable and above 3. In daylight, even with sunny weather, the dynamic road marking was clearly visible.

The colour of the light during day time is white but during night (dimmed situation) the colour is not homogeneous because of scattering of the light.

The product as tested on the A15 was sensitive for dust. Frequently cleaning with water was necessary to maintain the visibility.

The skid resistance as measured with the SRT was too low but the method was not suitable because of the profiled surface of the marking. The value for the brake delay compared to the ones for the asphalt and the thermoplastic road marking was also to low and could cause dangerous traffic situations especially for motor bikes.

10. Suggestions for technical specifications for dynamic road markings

After this pilot experiment the Ministry of Transport will come up with functional specifications for dynamic road marking products and the construction in the asphalt top layer so the industry can develop new products. At this moment a project team is evaluating all the gathered data of the measurements and the human behaviour experiments and will come up with a program of requirements for dynamic road marking products by the 1st of July 2000.

The topics for that program will be:

Skid Resistance Value / brake delay
Visibility and invisibility at various horizontal end vertical view angles
Height and transverse dimensions
Strength and resistance against traffic load and weathering (durability)
Reliability of control system

If possible a new experiment will take place in the year 2001 or 2002 were the dynamic road marking will be the tool to create a 3 lane layout on a 2 lane carriageway of a highway during rush hour. The specs must give a guarantee for the principal that the product will last long enough to justify the investment. They also must give the manufacturer the freedom to come with complete new innovative products as long as the functionality is granted.
Dynamic road marking is a new generation of road furniture for the nearby future.

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Curriculum Vitae

Name: Johannes (Hans) P.C.M. van der Aa, born in 1956 in The Netherlands

Graduated in 1980 as a Chemical Engineer (B.Sc.). Worked from 1981 - 1982 at AECI ltd in Modderfontein South Africa. In 1982 returned to The Netherlands and worked for some years in the chemical industry. Since 1991 working at the Infrastructure Laboratory of the Ministry of Transport in the Netherlands. Started to do research work on foundation materials and later specialised in road marking materials and measuring techniques. At the moment combining a laboratory and a consultant job in road marking products, application methods and measuring techniques.

From mid 1997 until now working on a project called “Infrastructure on demand” wherein dynamic road marking is just one of the topics which is tested in pilot experiments under traffic.

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