A “thinking road surface”

Dick de Waard[1], Karel A. Brookhuis[1], Magrita C. Noordmans[2], Jeroen H. Hogema[3], and Rob M. Visscher[4]
[1]Department of Psychology
University of Groningen
[2]Verenigde VTN Bedrijven
[3]TNO Human Factors
[4]Ministry of Transport, Roads to the Future project
The Netherlands

Abstract

Comprehensibility of an assistance system that should facilitate merging at places where a motorway lane ends was evaluated in the advanced driving simulator of the University of Groningen. Main components of the system called “Denkdek” (“Thinking road surface”) are electronic speed limit signs, arrows stimulating to merge, and moving light (LED) bars embedded in the road surface of the emergency lane. The system is made for motorways with a left lane drop. Goal of the system is to reduce speed and speed variability between lanes, and to introduce a small speed difference between the lanes. Drivers on the right-hand lane (i.e. the lane next to the emergency lane) should drive next to a moving LED-light bar and make space for traffic on the centre lane so they can merge. The space these vehicles leave behind on the centre lane can be used by vehicles on the left-hand lane.

Results showed that the system was effective in reducing speed, and on the right-hand lane average time-headway to cars-in-front increased. More traffic merged from centre to right if the system was switched on and in this way space on the centre lane was created. Drivers merged earlier compared with the situation where the system was off. This effect was also found with drivers who drove on the left-hand lane. In contrast, if the system was switched off a large proportion of drivers remained on the centre lane. Drivers judged driving *without* the system to be easier and smoother. Rides on the centre and right-hand lane were considered to be less effortful without the system. Rated acceptance of the system was neutral, usefulness of the system was evaluated as slightly positive. A high proportion (41%) mentioned potential distraction from other traffic by the system, and more than one in four said they ignored the system. Participants reported that the behaviour they were expected to display was neutral to clear. The driving simulator study has been followed by a field trial, which is at present being conducted.

In D. de Waard, K.A. Brookhuis, and C.M. Weikert (Eds.) (2004), *Human Factors in Design* (pp. 83 - 83). Maastricht, the Netherlands: Shaker Publishing.

Introduction

With the persistent increase in traffic volume motorways are becoming more and more crowded. Congestion is one of the main problems that follow the increase in volume. Very often congestion starts at points where one of the lanes of a motorway ends and traffic has to merge. A solution is to add lanes, but this is a high cost solution that can not always be applied in countries where space is scarce like in the Netherlands. An alternative approach is the optimisation of use of the present infrastructure by innovative techniques. In general this is adding “intelligence” by measuring traffic data and giving feedback, e.g. by electronic signs.

It is not only the congestion that is problematic at merge points. Undesirable driver behaviour such as anti social behaviour and dangerous manoeuvres are also found a merge points and are reported to raise stress level (Walters & Cooner, 2002). This should be avoided, not only because driver behaviour is unsafe, but also because this behaviour might aggravate congestion.

In the present study (De Waard et al., 2001, Hogema, De Waard, & Brookhuis, 2001) a system that guides drivers on a motorway where a third lane end was evaluated in a driving simulator. The evaluation focuses on clearness, behaviour, and mental effort of the driver. Obviously driver understanding of what they are expected to do is a condition for the success of such a new technique.

Method

A system that should guide road users when a lane ends was conceived and named “Denkdek” (“Thinking road surface”). In this phase the system is made for the transition of three to two lanes on motorways. Denkdek is supposed to facilitate and guide the merging process. The basis of Denkdek is that first traffic on the right hand lane is to reduce speed and by this lower speed increase headway. In this way gaps are created that can be used by traffic on the centre lane. On the centre lane vehicles are also slowed down and traffic merges right making use of the gaps on the right hand lane. Traffic that leaves the centre lane leaves behind gaps that can be used by vehicles from left-hand lane that ends further downstream.

Denkdek guides this process by the following:

- A prohibition for lorries to overtake other vehicles
- A different speed limit for each lane, 90, 85, and 80 km/h for respectively left, centre, and right-hand lane. Electronic signs on a gantry indicate these speed limits. This should lead to a lower mean speed and reduced variability in speed, and to a small difference in driving speed between lanes that should make merging easier
- Traffic on the right hand lane is guided by a running 12 metre white LED-light bar, embedded in the road surface on the emergency lane (see Figure 1). The LED-light is moving at the speed of the speed limit, thus appearing stationary to vehicles driving at that speed. The LED-light bar is announced on a billboard

with the image of a car next to the line and the text "Right-hand lane: remain next to light-trail"[•].

- At the point where traffic from the left-hand lane should merge right an arrow is shown on an electronic sign on the gantry. Above the centre lane the same arrow is shown, but this arrow is blinking.

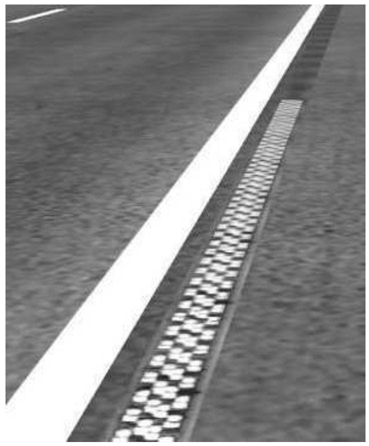

Figure 1. LED-light bar on the emergency lane as used in the driving simulator experiment

This system was evaluated in the University of Groningen driving simulator (Van Wolffelaar & Van Winsum, 1995). This is a fixed base simulator consisting of a car cabin (a BMW 525) with normal controls, connected to a Silicon Graphics Onyx computer. This computer calculated the road environment projected on a panoramic screen in real time, while at the same driver behaviour in terms of steering and speed control were registered.

The Denkdek was implemented in the simulator on a three to two lane motorway, as described above. Other traffic in the simulated world behaved "ideally", i.e. as the conceivers of the system had in mind. This was the starting point to see if participants understood what was required from them. Response to non-compliant behaviour of others was not subject of the study. Two levels of traffic volume were tested, 3500 and 4500 vehicles/hour. Both levels were below congestion level and could be handled by a two-lane motorway, i.e. after the lane drop. The higher level can be considered as "crowded" for a two-lane motorway. Mean speeds per lane and the distribution of the traffic volume over the three lanes varied with the traffic volume in accordance with real-world traffic flow observations (Hogema & Stel, 2001).

In total 32 men and women between 25 and 55 years of age participated in the experiment. All held a driving licence over 5 years and had an annual mileage of 10 000 km or more.

[•] in Dutch: "Rechterbaan: Blijf naast lichtspoor"

Between subjects factor was the order of conditions, within subject factors were:

- Approach lane (3 levels; left, centre, right-hand)
- Traffic volume (2 levels; low 3500, high 4500 vehicles/hour)
- System (2 levels; on/off)
- Repeated measures (2)

In total this amounts to 3 x 2 x 2 x 2 = 24 + 1 = 25 trials. The one additional passage was the very first time, intended to get an idea about naïve driver behaviour. No information was given before this ride, after the ride the system was explained (as can be expected as will be done by local publicity campaigns before implementation). In the “System off” conditions the electronic speed limit signs and the billboard announcement remained blank. There was accordingly no other speed limit than the national speed limit of 120 km/h.

Procedure

Participants started on the emergency lane of a single-lane road. That lane joined two other lanes resulting in a three-lane motorway. Participants either started on the right, centre, or left lane (see Figure 2). Instruction was to remain on that lane at least until passage of the first gantry. After that participants were allowed to change lane, but only to a lane to the right of them. After the first trial they filled out a questionnaire about the system comprehensability and they evaluated the smoothness of their lane change manoeuvre (if applicable). After this trial the goal of the system was explained. After each trial a rating of smoothness of the lane change manoeuvre and of mental effort (Zijlstra, 1993) was given. All trials ended on an exit, 400 m. after the third lane had ended (see Figure 2). After all experimental rides acceptance of the system was assessed (Van der Laan et al., 1997) and general comments were collected.

Variables and data analyses

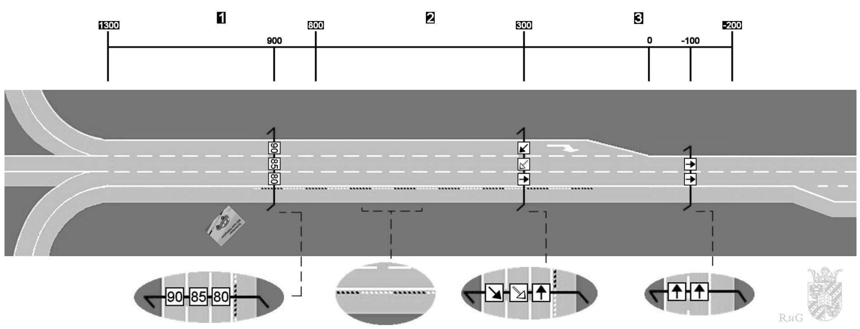

Figure 2. Top view of the experimental road network. Indicated are the positions of the gantries, the led-light, and three 500 m analyses segments, 1 (1300-800 m), 2: (800-300m) and 3(300- –200 m) where 0 m is the point where the third lane ends.

The road is divided into three 500 metre segments (see Figure 2). On each segment the following calculations on variables were performed: average and standard deviation of speed, average time-headway, and maximum deceleration. If applicable (i.e. only rides that started on centre or left hand lane): location of lane change, and accepted gap. On the right-hand lane mean and SD lateral position was determined to assess the effect of the led-light bar on lane control. Effects were statistically evaluated with help of SPSS 10.0 for Windows.

Results

In Figure 3 the average speed per segment and lane is shown. Although a statistical main effect of volume was found, the pattern for both conditions was the same and only data of the high-volume condition (4500 vehicles/h) are shown.

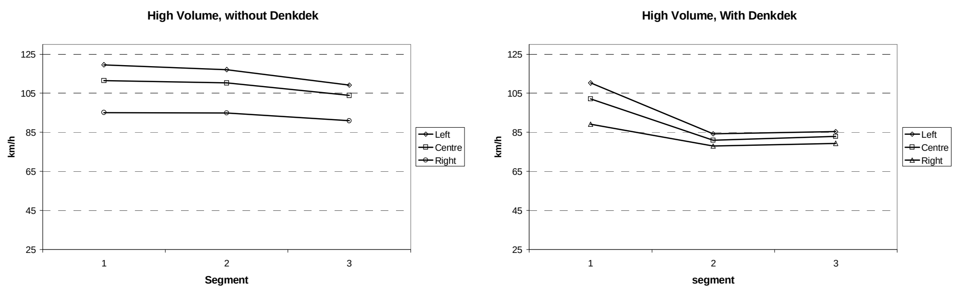

Figure 3. Left-hand figure: Without Denkdek, right-hand figure: with Denkdek. Average speed is displayed per segment and per (approach) lane.

Main effects of Lane (Hotellings $T = 55.5$, $p < 0.001$), Segment (Hot. $T = 49.1$, $p < 0.001$), System ($F(1,30)=5299$, $p < 0.001$), and Volume ($F(1,30)=14.4$, $p < 0.001$) on driving speed were found. If Denkdek was switched on the average speed was lower. This obviously is related to the imposed speed limit of 80/85/90 km/h and becomes visible in Segment 2. Average speed on the right-hand lane is lower than on the centre lane, on the centre lane speed is lower than on the left-hand lane. This is as expected in particular as participants were not allowed to overtake other vehicles and other traffic kept to the speed limit. Standard deviation of speed was slightly higher in conditions where the system was switched on. In the control condition (system switched off) strongest decelerations were found in the third segment, where the third lane ends. In the Denkdek conditions participants decelerated earlier, in line with the average speed pattern.

Time headway was assessed to the car in front in the same lane (Figure 4). Results show that average headway is larger if Denkdek is switched on ($F(1,31)=8.33$, $p < 0.01$). As intended, time headway increases on the right hand lane if cars are driving next to the running led-light bar. The increase in headway in the control condition on this lane is minimal. No differences were found between the two Volume conditions. Figure 4 clearly shows that time headway decreases from left to right-hand lane.

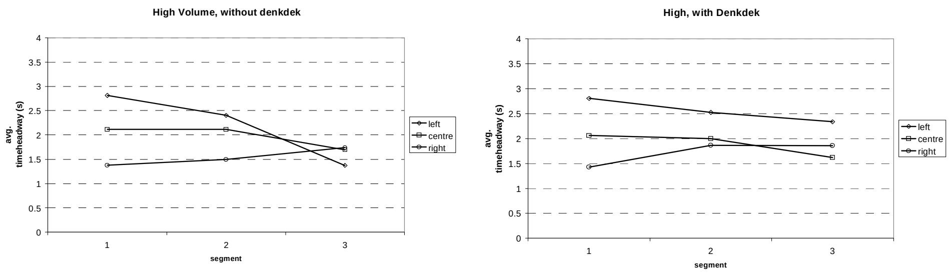

Figure 4. Left-hand figure: Without Denkdek, right-hand figure: with Denkdek. Average time headway (seconds) is displayed per segment and per (approach) lane.

In Figure 5 the point where participants (first) changed lane is depicted. The thick lines (Denkdek 'on') show that participants changed lane earlier, and more in the same area. Also *more* drivers changed lane from centre to right, in the 'Denkdek off' condition about 65% remained on the centre lane opposed to 6% in the 'Denkdek on' condition. After changing lane from left to centre, the new time headway to the car in front is 1.2 s. if the system was switched off opposed to 1.6 seconds with Denkdek on ($F(1,27) = 18.99$, $p < 0.001$). The car behind the participant's car was forced to an average time-headway of 1.3 s. (system off) to 1.8 seconds (Denkdek on). These comparisons are not so easily made for centre to right lane movements as only 35% changed lane if the system was off. No effect of system was found, only for the car behind the participants (same pattern as left to centre lane movements; $F(1,9)=7.93$, $p < 0.02$). The accepted gap was calculated for left to centre lane movements only.

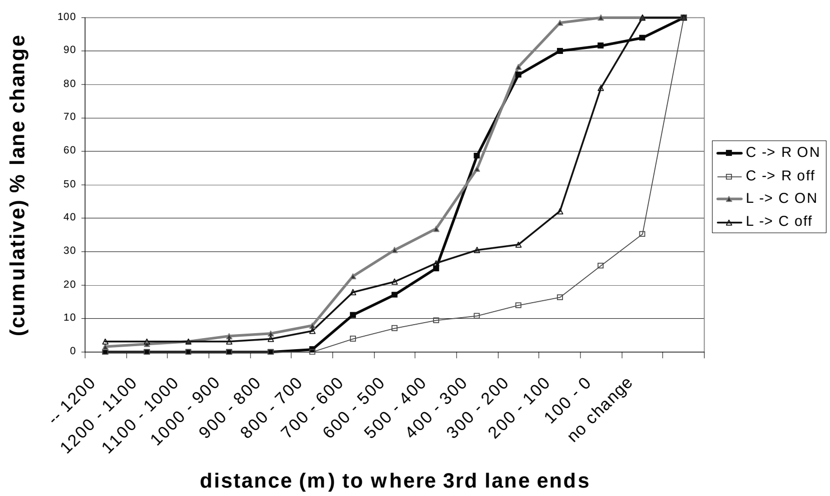

Figure 5. Position where participants changed lane (cumulative) indicated as distance from the point where the third lane ends. On (thick lines)/off (thin lines) means Denkdek on/off, L = Left-hand lane, C= Centre lane, R = Right-hand lane.

There was a marginally significant effect of system ($F(1,27) = 3.84$, $p < 0.07$), accepted gaps were 87 metres (with Denkdek) and 75 metres (without Denkdek).

Only on the right-hand lane the LED-light bar was visible, and for that reason mean lateral position and swerving (SD Lateral position) were compared between the Denkdek “on and off” conditions. The led-light had no effect on average position on the lane, the mid of the car’s position was 0.1 metres left of the centre of the lane. There was a marginal significant effect on SDLP (‘swerving’, see e.g. Brookhuis, De Vries, & De Waard, 1991) on Segment 2 (the led-light area), drivers swerved less if the led-light was on (0.16 opposed to 0.20 m., $F(1,30)=3.06$, $p < 0.09$). Distance to the led-line was on average 11 metres, SD of this distance was 5 metres indicating that the running light was well followed (which could be expected as other vehicles obeyed the speed limit and followed the LED-light).

The very first time participants completed a trial Denkdek was switched on while they had not received information about the system. During this passage 13% did not merge, which is slightly higher than the 6% who merged later, but by far not as much as the 65% who did not merge later if Denkdek was switched off. Driving behaviour otherwise such as speed and position of lane change did not differ from later trials, when they had received full information about the system.

Self-reports

‘Ease’ of the merge manoeuvre was assessed on a 5 point Likert scale and values were averaged over repeated measures. Main effects of System ($F(1,31)=16$, $p < 0.001$) and Lane ($F(2,31)=3.61$, $p < 0.04$) were found. As can be seen in Figure 6, driving while merging, or while other traffic was merging was judged to be less easy if Denkdek was switched on.

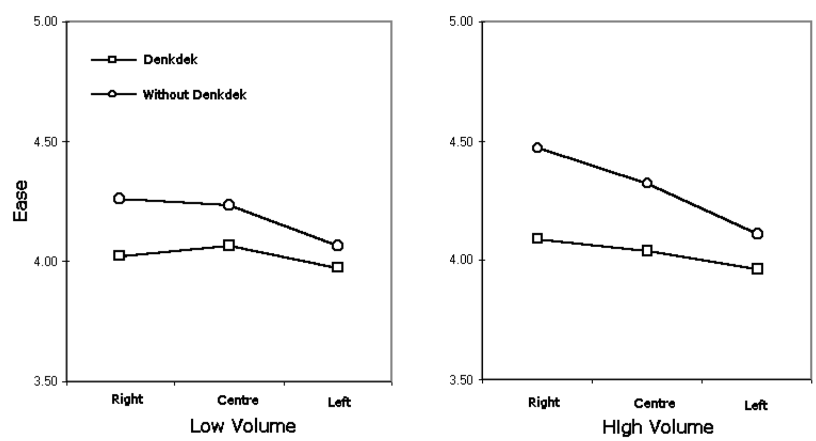

Figure 6, Self-reported ease of manoeuvre per lane for the two traffic volumes. The scale runs from 1(not easy) to 5 (easy)

After each trial mental effort was rated on the Rating Scale Mental Effort (RSME, Zijlstra, 1993). Analyses of variance showed main effects of repeated measures ($F(1,31) = 11.3$, $p < 0.001$), of System ($F(1,31) = 14.7$, $p < 0.001$) and Lane ($F(2,30) = 8.3$, $p < 0.001$). Averages are shown in Figure 7. Driving with Denkdek was rated more effortful, the second rates were rated as less effortful. Driving on the left-hand lane was judged more effortful than on the centre ($t(31)=4.07$, $p < 0.001$) and right-hand lane ($t(31)=2.32$, $p < 0.05$). Driving on the centre and right hand lane did not differ in terms of rated invested effort. Rides on the right-hand lane were evaluated as requiring more effort with Denkdek as compared to without the system.

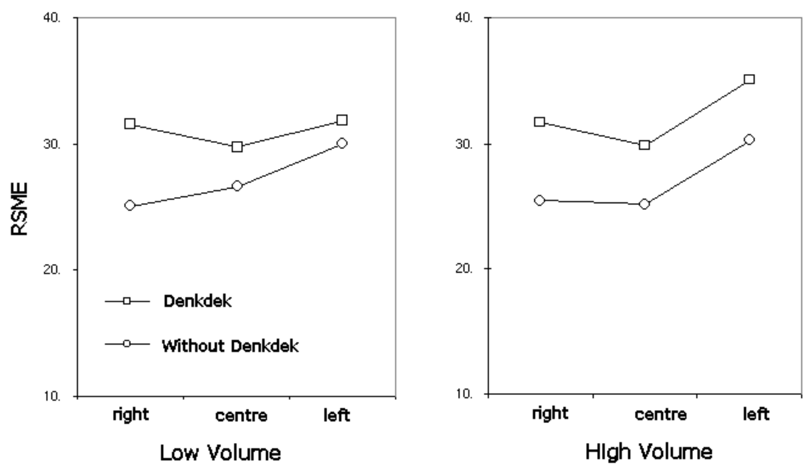

Figure 7. Average ratings of invested Mental Effort by Volume, System, and Lane. A RSME rating of 10 equals "almost no effort", a rating of 40 equals "some effort"

After the test rides ratings of acceptance on a standard acceptance scale (Van der Laan et al., 1997) and comments about Denkdek were collected. The system was judged neutral in terms of Pleasantness (+0.10 on a scale from –2 to +2), and slightly positive on Usefulness (+0.48 on a scale with the same range, see Van der Laan et al., 1997).

Comments about the system were categorised and are listed in Table 1.

Table 1. Comments about Denkdek (N=32)

Category	Frequency	Proportion
System is distracting, diverts attention from other traffic	13 x	41%
System helps to merge, adapt speed	9 x	28%
Did not pay attention to system, ignored the system	9 x	28%
System is wearying	9 x	9%

Discussion and conclusions

Goal of the driving simulator experiment was to assess driver response to, behaviour on, and opinion about *Denkdek*, a merging assistance system. With Denkdek drivers drove at a slower speed. This is at least partially due to the lower speed limit that was imposed, the instruction not to overtake other vehicles, and the behaviour of other traffic (i.e., fully compliant with the system). However, in this way the intended speed difference of 5 km/h per lane was accomplished. With Denkdek much more drivers (94%) merged from the centre lane to the right-hand lane opposed to only 35% who performed this manoeuvre without Denkdek. In this way space on the centre lane was created. However, with Denkdek lane changes took place further away from the point where the third lane ended than without the system. On the right-hand lane the running led-light was well followed. Again, this may be caused by the prohibition to change lane to overtake vehicles, and the other traffic present behaved correctly. Effects of traffic volume were limited to an overall lower driving speed in the high volume condition.

Overall opinion about and acceptance of the system was positive. With Denkdek lane change manoeuvres were judged to be somewhat less easy to perform and to have required more effort. Denkdek is a new system, and possibly with increased familiarity with tye system theses differences may decrease. However, a large proportion (41%) mentioned distraction by the LED-light as a potential problem, and one out of four said to have ignored the system.

The results of the simulator study were considered to be positive enough (in particular the fact that no shift towards dangerous behaviour was found) to implement and test Denkdek in the real world (Figure 8).

Compared with the simulator study the following a few details were was changed. The length of the led-line bar was increased from 12 to 15 metres for lorries, and the text on the billboard (originally ‘Right-hand lane: remain next to light-trail’) was changed into ‘Give each other space, follow the light-trail’•. The flashing arrow on the gantry above the centre lane is no longer flashing, and the speed limits indicated on the gantry were changed to 80/90/100 km/h instead of 80/85/90. Reason for these changes were legal restrictions. Another importantant difference is that at the ledlight area there is an exit. There are hardly any motorways in the Netherlands with a lane drop without such an exit preceding the point where the fast lane ends. From spring until autumn 2003 Denkdek is evaluated on driver behaviour and effects on traffic flow, driver opinion about the system is assessed by surveys.

Acknowledgement

This study was completed in co-operation with TNO Human Factors in Soesterberg and was commissioned by The Ministry of Transport. The intellectual ownership of Denkdek is reserved to Verenigde VTN Bedrijven. Website: www.denkdek.nl

• In Dutch ‘Geef elkaar de Ruimte, Volg het Lichtspoor’

Figure 8 Picture of the led-light bar implemented on the A9 motorway in the Netherlands°

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° See also http://extras.hfes-europe.org

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