CHEVRON MARKINGS ON FREEWAYS: EFFECT ON SPEED, GAP AND SAFETY

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Author:
Mr. Poul Greibe
M.Sc., Civil Engineer.

Trafitec
Research Park, Scion-DTU
Diplomvej 376
2800 Lyngby
Denmark

Phone: +45 2524 6734
E-mail: pgr@trafitec.dk

ABSTRACT

45% of all injury accidents on Danish freeways are categorised as accidents with vehicles driving in the same direction. On a year basis, these accidents results in more than 120 killed and injured persons. Rear-end accidents typical occur in situations with very short headways and/or in combination with high speed levels.

Inspired by positive results from the use of chevron markings in UK and France, a trial of chevron markings on Danish freeways, to help drivers to choose a safer distance to the vehicle in front, was initiated by the Danish Road Directorate in 2007. The chevron markings were establish on 5 road sections (each 4 km long), and consist of a series of white arrowheads on the road surface at 36 m intervals. The chevron markings were accompanied by road side signs advising drivers to keep a distance of 2 chevron markings to the vehicle in front.

In order to evaluate the use of chevron markings, traffic flow, speed and gaps were measured by use of loop-detectors at 3-4 locations on each road section. One detector was situated upstream from the markings; one detector on the road section with markings and one or two detectors were situated downstream from the markings (4-12 km downstream from the chevron markings). Data on speed, traffic flow and headways were collected 1 month before and 2 month after the installation of chevron markings. In addition, in order to estimate the long term effect, the plan is to collect traffic data again 2 year after the installation.

The short-term effect by chevron markings (2 month after) showed significant fewer vehicles with small gaps (gap<1sec) compared to the before situation. The largest reduction was found in the left lane. The number of vehicles with gap less than 2 seconds was also reduced, but the reduction was smaller. Speed was reduced slightly. In general, the largest effects on gaps and speed were found on road sections with chevron markings, but also an effect 4-7 km after the marking (downstream) could be found. Further downstream (>10 km), no effect from the markings could be measured. The long-term effect (2 year after) has not been estimated yet.

A questionnaire survey among drivers indicated that the purpose of the markings was understood, and that majority of drivers have changed behaviour (greater gap to vehicle in front).

A small before-after accident analysis, based on two road section with chevron markings on freeways established back in 2004, showed a reduction in accidents. The analysis is based on very few accidents though, and the estimate is uncertain. The accident analysis will be repeated again using a longer before-after period.

1. INTRODUCTION

In the Danish traffic act, it is stated that “the distance to vehicles in front should be adjusted, in order to reduce risk of collisions, in case the vehicle in front reduce speed or stops”. However, drivers tend to have insufficient headways when driving on the freeways which lead to accidents. 45% of all personal injury accidents on the Danish freeways involves vehicles driving in the same direction and 25% are pure rear-end accidents. A contributory factor in rear-end accidents are to short distance between vehicles compared to the speed.

In the 1990’s, trials with chevron markings on freeways were tested in UK and France and the results were mainly positive (3, 4). The distance between vehicles were increased and rear-end accidents were reduced. Based on these experiences, the Danish Road Directorate decided to test the use of chevron markings on Danish national freeways.

In 2004, three road sections were equipped with chevron markings, and in order to increase the experience, five new test road sections were equipped with chevron markings in 2007. This paper summarises the overall finding from an evaluation programme that was conducted in 2008 (1).

2. TEST ROAD SECTIONS

A total of five freeway road sections were chosen to be part of the trial. The criteria used to indentify suitable locations were:

- The presence of stationary loop detectors in order to collect traffic data
- A suitable traffic density with no traffic flow break downs.
- 4 lane freeway (2 lane in each direction)
- No future plans for reconstruction or re-pavement/resurfacing
- The presence of rear-end accidents

The five test road sections are shown in table 1.

TABLE 1. Test road sections with chevron markings.

Test road section	Freeway	Location (city)	Direction	AADT (vpd)	Start (km)	End (km)	Length (km)
No. 1	M60	Horsens	North	22,000	131.1	135.0	3.9
No. 2	M60	Horsens	South	23,000	140.0	136.0	4.0
No. 3	M30	Køge	North	21,000	47.4	43.6	3.8
No. 4	M30	Køge	South	21,000	42.2	45.9	3.7
No. 5	M40	Aarup – Ejby	West	29,000	187.6	191.6	4.0

The length of test road sections with chevron markings varies between 3.7 and 4.0 km and the traffic flow in the analysis direction varies between 21,000 and 29,000 vehicles per day. The speed limit on the test section is 130 km/h (general speed limit on freeways in Denmark). Test section 3 and 4 have no on/off ramps while the remaining sections have one on/off-ramp located on the road section. Heavy vehicles are not allowed to overtake (at any time) on test section 5, while overtaking by heavy vehicles are prohibited from 06-18h on section 3 and 4.

The chevron markings were established in October-November 2007. The markings are shaped as chevrons and placed in both lanes with a distance of 36 m, see figure 1. When driving 130 km/h (the speed limit), the

driver must see 2 chevron markings, which equals a distance of approx. 2 seconds, to the vehicle in front. Upstream (400m) from the road section with chevron markings, information signs are placed with the description: "Road marking trial ahead". On the road sections with chevron markings there are two yellow signs with the message: "Keep the distance – two chevrons". In addition to the information signs, the Danish Road Directorate has informed road users, the press etc. about the trial via the medias.

FIGURE 1. Road section with chevron markings. The warning sign (with exclamation mark) was placed 400m before the chevron markings section giving information about a road marking trial ahead. The yellow sign gives information on how to use the chevrons markings.

3. DATA COLLECTION AND PROCESSING

Traffic data (vehicle by vehicle data) have been collected by use of loop detectors placed:

- on the road section with chevron markings
- up-stream from the chevron markings (used as control section)
- down-stream from the chevron markings

One set of detectors were placed on the chevron road section in order to measure the effect on driver behaviour from the chevron markings, see figure 2. The up-stream road section is used as a control section in order to control the observed effect from general trends in traffic flow, speed, gap-distribution etc. The detectors on the control section are placed with a distance of 1 to 6 km from the chevron markings. The down-stream section has one or two loop detectors (one loop detector on the majority of test sections) in order to estimate how far from the chevron markings the driver behavioural effect can be seen. The down-stream loop detectors are placed 2 to 12 km down-stream from the chevron markings.

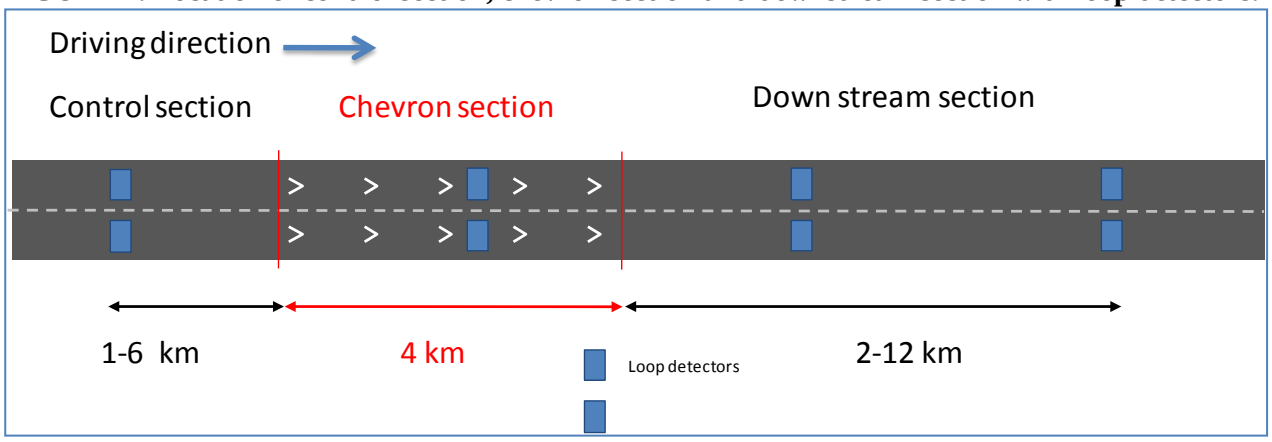
Traffic data are based on a 4-day period before the installation of chevron markings and a 4-day period after the installation. Only weekdays with no rain or traffic incidents are included. The before period is 1-2 weeks before the installation and the after period is 4-8 weeks after.

The evaluation is mainly based on three parameters:

Speed - average travel speed for passenger cars (km/h)
G<1sec - share (%) of vehicles with a gap less than 1 second to vehicle in front
G<2sec - share (%) of vehicles with a gap less than 2 second to vehicle in front

The effect has been estimated as absolute changes from “before” to the “after period” on each road sections, and as relative changes (change in relation to control sections).

FIGURE 2. Location of control section, chevron section and downstream section with loop detectors.



4. CHANGES IN SPEED AND SMALL GAPS

4.1 Short term effect

The observed average short term effect (4-8 weeks after the installation) is shown in table 2. The figures are average values based on all five test sections for the entire before/after period.

On the control section (upstream from the chevron markings), it was found that small gaps (G<1sec) was reduces by 9-10%. This was a surprise since it was expected that no effect from chevron markings could be found upstream from the chevron sections. In order to confirm these results, additional control sections (not situated near chevron markings) were studied. The new control sections showed similar results and based on further analysis it has been concluded, that changes in speed and gap-distribution has a seasonal variation. In late autumn (October-December), the speed is lower and the share of small gaps is lower compared to September. This seems to be a general phenomenon on all freeways and has nothing to do with the installation of chevron markings.

The observed effect on the road sections with chevron markings showed reduction in speed (3-4%) and a reduction of 16-19% in gap less than 1 sec. The effect downstream from the chevron markings is somewhat lower.

TABLE 2. Observed average effect on speed and gap on the control section, chevron section and downstream sections (before/after).

		Upstream (control section)			Chevron section			Downstream I (1-4 km from chevron)			Downstream II (7-12 km from chevron)		
Lane	Parameter	Before	After	+/- %	Before	After	+/- %	Before	After	+/- %	Before	After	+/- %
Right	Speed (km/h)	111	110	-1%	114	109	-4%	111	109	-2%	111	110	-1%
	G<1sec (%)	6	5	-10%	5	4	-16%	6	5	-11%	5	4	-9%
	G<2sec (%)	20	19	-5%	21	19	-8%	21	20	-4%	18	17	-5%
Left	Speed (km/h)	120	118	-2%	121	117	-3%	120	118	-2%	117	116	-1%
	G<1sec (%)	24	22	-9%	26	21	-19%	23	20	-13%	25	23	-10%
	G<2sec (%)	51	50	-2%	52	50	-3%	50	49	-2%	51	49	-2%

In table 3, the observed relative average effect on speed and small gaps is estimated. The figures are average values based on all five test sections and takes into account the general changes that have been observed on the control sections. For each estimated effect in table 3, the number of test sections that have a significant effect (5% level of confidence) is also shown. A "÷" indicate a significant decrease for one test section, "+" indicate a significant increase for one test section and "n" indicate a non significant effect for one test section. For instance, "÷÷÷÷÷" indicate a significant decrease for all five test sections.

The average effect on the chevron sections (compared to the control section) shows a 3 km/h reduction in speed for the right lane (significant decrease on all five sections) and a 1 km/h reduction in speed for the left lane (three sections with significant reductions and two sections with no significant effect).

The effect on G<1sec is a reduction of 7-11%. The largest effect is found in the left lane (-11%) where all five sections have a significant decrease. The effect on G<2sec is an average reduction of 1-4%, but only a few sections showed significant effects.

In general, the effect downstream from the chevron markings is somewhat lower and more heterogeneous. 7-12 km down-stream from the chevrons, the effect is more or less none existing.

TABLE 3. Estimated average effect in relation to control sections.
The number of ÷, + or n's indicate the number of sections with significant decrease, significant increase or no significant effect.

Lane	Parameter	Chevron section	Downstream I (1-4 km from chevron)	Downstream II (7-12 km from chevron)
Right lane	Speed (km/h)	-3 km/h ÷÷÷÷÷	-1 km/h ÷÷÷ n +	0 km/h ÷ n +
	G<1sec	-7% ÷ nnnn	-1% ÷ nnnn	0% ÷ nn
	G<2sec	-4% ÷÷ nnn	+1% ÷ nnn +	0% ÷ nn
Left lane	Speed (km/h)	-1 km/h ÷÷÷ nn	0 km/h ÷÷ n ++	+1 km/h ÷ ++
	G<1sec	-11% ÷÷÷÷÷	-4% ÷÷ nn	-2% ÷ nn
	G<2sec	-1% ÷÷ nn +	0% ÷ nnnn	-1% ÷÷ n

Speed and gap distribution depend highly on traffic flow and in order to study these relations in more detail, a number of speed-flow curves and gap-flow curves have been produced for the test road sections. Figure 3 shows an example from the chevron road section on test road 4. It illustrates the observed speed-flow relation before and after the installation of chevron markings for left and right lane. The drop in speed (approx. 2-4 km/h) is present at all flow levels, but seems to increase at high flow volumes.

FIGURE 3. Example of speed-flow curve (before/after) for test road 4.

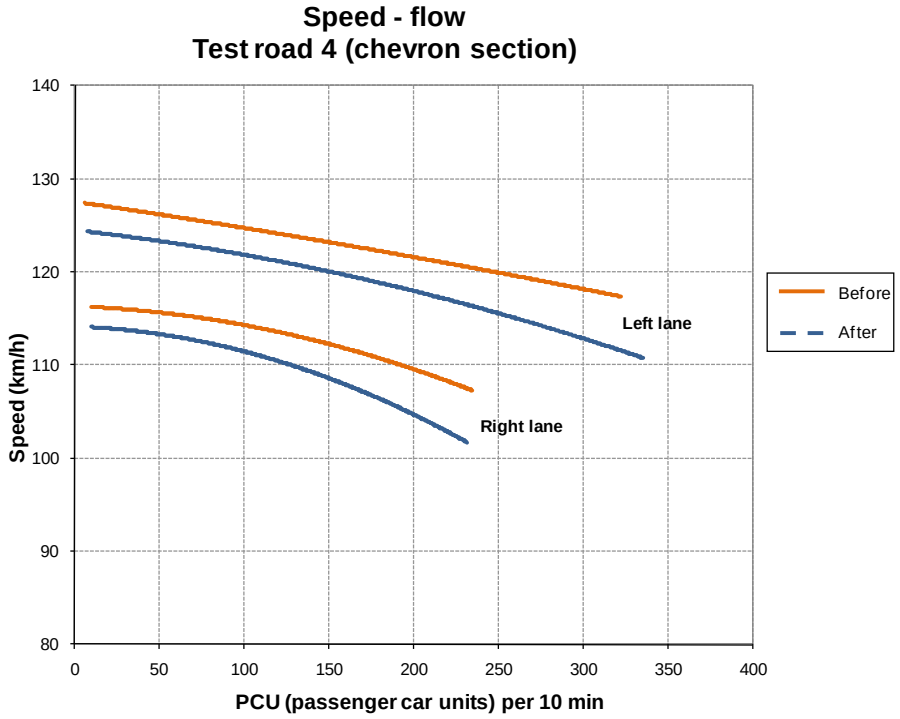
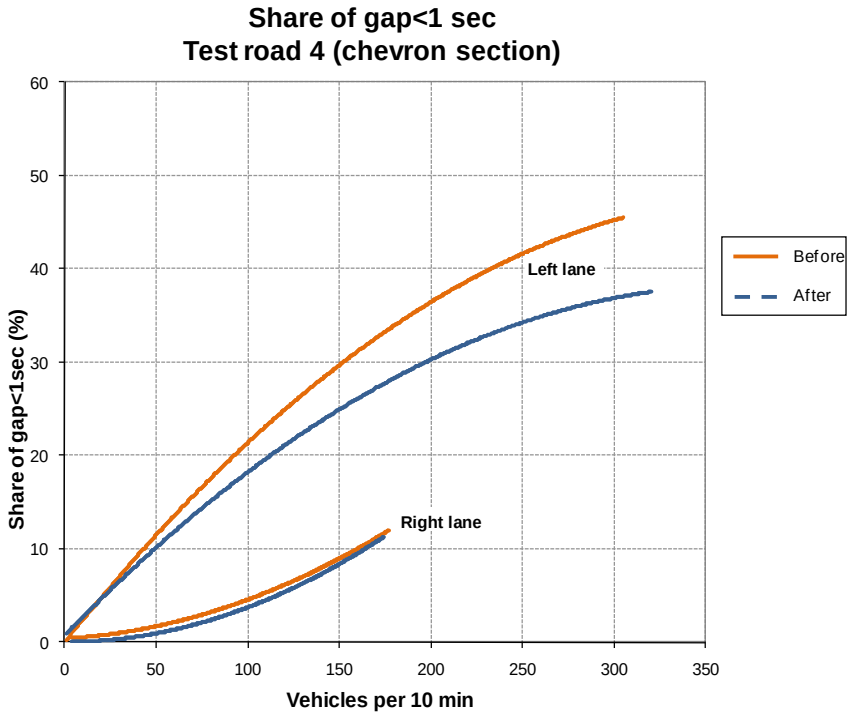


Figure 4 shows the observed gap-flow curve before and after the installation of chevron markings. At low traffic volumes, the share of small gaps (<1sec) is close to 0%. The share of small gaps increases up to

more than 40% in the left lane and 10% in the right lane when the traffic volumes are increased. The effect from before to after is clearly shown for the left lane, but not significantly for the right lane.

FIGURE 4. Example of gap-flow curve (before/after) for test road 4.



5. ROAD USER FEED BACK

The road user experience and satisfaction with chevron markings have been studied by use of telephone interviews. A total of 916 respondents were asked about their experience and understanding of the chevron markings. The interviews were conducted 4-6 month after the installation. The main results are summarised below:

- 80% of the respondents have noticed the chevron markings on freeways

Among these 80% (that did notice the chevron markings), it was found that:

- 96% knew the purpose of the markings.
- 88% said that the marking made them keep a distance of two chevrons signs, or 2 seconds to the vehicle in front.
- 60% experience that other roads users keep a greater distance
- 63% think the chevron marking to be “a great help” or “some help” (to keep a safe distance)
- 30% answered that the chevron markings was neither “to some help” or to “any inconvenience”
- 3% felt “inconvenience” by the chevron markings.

The overall results indicate that road users are mainly positive about the use of chevron markings.

6. PRELIMINARY SAFTY EFFECT

As mentioned earlier, two road sections with chevron markings were established in 2004. A minor accident analysis (before-after) have now been conducted based on a 4 year before period (1. April 2000 – 1.April 2004) and a 4 year after period (1. June 2004 – 1. June 2008). The observed accidents before and after the chevron markings were installed are shown in table 4. All types of accidents on the road section with chevron markings are included in the study.

In general, the number of accidents is too small to measure any significant safety effect. In total, there were 3 personal injury accidents in the before period and 1 in the after period. The corresponding numbers for damage only accidents are 2 before and 1 after.

The table also shows before/after figures for slight damage only accidents. These types of accidents are under normal conditions excluded from the safety analysis since they are reported very differently by the police. There are 4 slight damage only accidents in the before period and 6 in the after period.

The general accident trend for other similar freeway road sections in the same period shows a slight decrease in personal injury accidents but a significant increase in damage only accidents. The chevron road sections tend to perform slightly better compared other similar roads sections. However, the number of accidents is still too small to estimate the safety effect yet.

It should be mentioned, that no significant changes in the accident picture (composition of accident e.g. rear end/single accidents) was found.

A more extensive before/after safety study are planned to be conducted in 2012 when the five new test sections have been in place for a longer period.

TABLE 4. Observed police recorded accidents before/after installation of chevron markings on two freeway road sections.

Police recorded accidents:	M20		M70		Total	
	Before	After	Before	After	Before	After
Personal injury	2	1	1	0	3	1
Damage only	2	1	0	0	2	1
Total	**4**	**2**	**1**	**0**	**5**	**2**
Slight damage only	*3*	*5*	*1*	*1*	*4*	*6*
Total – all accidents	7	7	2	1	9	8

7. CONCLUSION

The Danish Road Directorate has installed chevron markings on a number of freeway road sections. The short term effect on the chevron road sections shows:

- Reduced speed (1-3 km/h)
- Reduced share of vehicles with gap<1sec (7-11%)
- The left lane has the largest reduction in small gaps

The observed effect is also seen 1-4 km down-stream from the chevron markings. However, the effect is smaller. 7-12 km down-stream from the markings the effect is gone.

Even though the share of small gaps (<1sec) is reduced by the chevron markings, there is still a large potential for further reductions. The share of vehicles with a gap<1sec in the left lane are at some road section still 20-30%.

The road user feed back are mainly positive. The drivers understand the purpose of the markings and they rate the markings as helpful to keep a safe distance to vehicles in front.

A preliminary before/after accident study indicate that the markings have positive effect on safety. The effect is however still uncertain due to limited accident data.

Further studies are needed to verify the findings regarding driver behaviour. It is recommended to study the long-term effect from the chevron markings on speed and gap-distribution. Also the accident analysis should be conducted again when more accident data is available. Another issue that needs further research is the optimal length and frequency of road section with chevron markings in order to achieve the best effect. The tested road sections in this study were 3.7-4.0 km long (approx. 2 min drive) but the optimal length is unknown. Chevron markings have so far only been used on a few locations and it must be considered how often chevron markings can be used on a freeway sections before the effect will be reduced.

8. REFERENCES

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