02-03-2005/Paper number GD05-0006

The 3rd International Symposium on Highway Geometric Design – Chicago June 2005

Development of Speed Management Methods for Use on Rural Roads

Lene Herrstedt
Director, Civil Engineer, Ph.D.
TRAFITEC – Research, Development & Innovation
Research Park SCION-DTU
Diplomvej 376, 2800 Kgs. Lyngby
Denmark
Email: lh@trafitec.dk
Phone: +45 25 24 67 33

ABSTRACT
Denmark and other European countries have a growing road safety problem on rural roads. About 70 % of road fatalities and 45 % of road casualties in Denmark are on rural roads and high speed is a fundamental factor. Speed limits are exceeded more and more. Speed control outside build-up areas is very problematic. This is the background for the project concerning development of speed management methods for use in rural areas initiated by the Danish Road Directorate.

A Catalogue of Ideas for potential speed management measures for use in rural areas has been worked out. Ideas have been collected from national and European traffic experts and practitioners. In parallel a dialogue between *traffic psychologists* and *traffic engineers* has been mobilised with the purpose to discuss and describe the general principles for speed behaviour.

Some of the ideas from the Catalogue have been selected for implementation. Special marking along the centre lines on regional rural roads has been established. A narrow rural road – including three road sections with signed speed limits on 40 km/h, 50 km/h and 60 km/h has been re-designed by introduction of the "2-1"(two minus one) cross section profile supplemented by speed reducers - designed as narrowing - and road surface treatments. Another rural road has been provided with different electronic devices combined with rumble strips and coloured road surfaces. Variable message signs have been installed at intersections and speed detection has been connected to illumination of signs in horizontal curves.

1. INTRODUCTION

Denmark and other European countries have a growing road safety problem on rural roads. Almost 70 % of road fatalities and 45 % of casualties in Denmark are on rural roads. High speed is a frequent factor in causing accidents and high speeds leads to more serious injuries (6), (7), (8), (9). The latest published results from the permanent counting stations on rural roads analysed by Danish Road Directorate (10) show, that the mean speed on Danish rural roads, with speed limit 80 km/h, was 84 km/h in 2002. Speed limits are exceeded more and more. In 2002 the limits were exceeded by 61% of cars and vans and 14 % exceeded the limit by more than 20 km/h. Speed control outside build-up areas is problematic mostly because of missing political support and acceptance. Speed adaptation is central for increasing road safety.

This is the background for the project concerning development of speed management methods for use in rural areas initiated by the Danish Road Directorate.

2. THE VISION

Road safety is based upon a balanced interaction between the road users, the vehicles and the infrastructure. A safe infrastructure depend on a road user adapted design of the whole road environment including: geometric design, markings, signs, lightning, equipment, plantings, road surface and information technology, management of traffic and speed, traffic laws and rules for the use of infrastructure.

“The self explaining and forgiving road” should be the vision for the safe road infrastructure in the future. The aim should be to create a simple and unambiguous, clear and understandable, readable and recognisable traffic situation – easy to handle for the road users – without too many distractions and information overload – and leaving no doubt about the reasonable speed level, the give way situation, location and movement of other road users around. The aim is simplicity and clearness in stead of complexity and ambiguity! (3)

Whatever we do about design - including use of information technology - with the aim to help the road users to manage traffic situations in a safe manner – road users will make mistakes and accidents will occur. But mistakes in traffic should not mean “sentenced to death”! The vision of “The self explaining and forgiving road” is a new way of thinking in planning and designing road infrastructure.

From research and development we already have a lot of knowledge to start implementing the first generation of “The forgiving road” based upon a systematic implementation of road safety measures to minimize the consequences: implementation of brake-away-systems, remove dangerous obstacles along the roads, balance the distance to objects along the road to the level of speed, installation of crash cushions at strategic locations, supply road shoulders with moderate slope angles to avoid cars to roll over in run-off accidents, installation of road barriers, use of warning systems to wake up the driver etc. And the most important of all: speed management! The higher speed the more serious will the consequences be from mistakes in traffic!

Speed management techniques for urban areas have been developed, evaluated and implemented during more than three decades in Denmark. Tools and concepts are very well described and tested. Recommendations have been included in the Danish Guidelines for Urban Areas for several years already. Handbooks for planning and implementation process are available. This is one of the main reasons for the very positive development in road safety for urban areas in Denmark during the last ten years.

A challenge for the future is the question on how we manage speed on rural roads and arterial urban roads.
A vision for the future is a change from a system based upon general fixed speed limits to a system based on differentiated and dynamic limits adapted to the current traffic situation. This must be done by combining road design, road equipment and use of new technology.

3. DEVELOPMENT OF SPEED ADAPTATION TOOLS FOR USE ON RURAL ROADS

A Catalogue of Ideas (*1*) of speed adaptation tools for use in rural areas has been worked out. Ideas have been collected from national and European traffic experts and practitioners. Progress in this field depends on a fruitful dialogue and co-operation between engineers and traffic psychologists. In parallel with collecting ideas for potential speed management tools - a dialogue between *traffic psychologists* from the Swedish National Road and Transport Research Institute and Institute of Transport Economics (TÖI) in Norway and *traffic engineers* in Denmark - researchers and practitioners - has been mobilised with the purpose to discuss and describe the general principles for speed behaviour. So far a short note (*2*) describing general principles for speed behaviour has been worked out as a part of the catalogue. The note will be extended during the work by adding new gained experiences.

Speed behaviour - general principles

Road users often have a spontaneous and unconscious perception of information from surroundings. Lines create visual perspectives. Objects placed close appear as bigger objects compared to objects placed in longer distances – even though it is not the case. Road users rely mostly on visual information. The visual design of road environment is therefor very important.

The perception of speed depends on the movement related to the surroundings. Two drivers approaching an intersection at right angles might percept each other as standing still. Speed is perceived as higher in relation to objects very close compared to objects far away. When moving forward in traffic the optical focus will be standing still while all other objects in the view field will be seen moving in an optical expansion from this focus point and the size of objects will visually increase. The higher speed the faster the optical expansion process will be. This is known from traffic situations – ex. when the car driving in front is slowing down. Studies have shown a general tendency of underestimating own speed among drivers. Choice of speed depend on many factors ex. perceived danger, mental load and overload, physical discomfort because of vibration and noise, habits and unconscious speed adaptation (speed generalisation). The visual perception of the traffic environment is a very strong factor.

Mental overload may lead to speed reduction as compensation. Monotony and underestimation of drivers – ex. when driving on a monotone boring road – turn on “the autopilot” and may lead to increased speed to break the monotonous situation and “turn off “ the autopilot again.

Humans are supplied with a natural curiosity. We continuously observe the close surroundings but mostly this search of information is unconscious. When we face a non recognizable situation and we need to adapt a new environment or new situation our consciousness is turned on. A varied and stimulating road design keep the driver attention alive. Those principles can actively be used in road design by aiming at developing series of road sections with limited sights. New road sections will be opened up to the driver when leaving one section and enter the next. Every time a new section is opened up it stimulates the curiosity of the driver. Driver attention must continuously be aroused. An example to illustrate the principles described could be the implementation of a roundabout. A new road section open up a new road environment after passing the roundabout.

General principles for human factors related to speed perception should be actively utilized in road design. The designer should aim for creating a varied road environment with a balanced demand of mental load and a comfortable rhythm for the drivers.

4. THE CATALOGUE OF IDEAS

Some of the tools described are new “ideas” while others are known – more or less - but not necessarily evaluated. Some of the ideas from the Catalogue have been selected for implementation and evaluation in pilot studies and more pilot studies expect to follow during the next years.

The Ideas include different designs for speed zones in rural areas and road sections based upon “2+1” and “2-1”, marking of curves and transition zones, physical and electronic measures for spot wise speed reduction on road

sections, speed reducing designs at intersections, different kinds of technical measures as ex. VMS, reflectors/lamps and three dimensional visual markings and ITS technology for speed adaptation.

Some examples of the most untraditional ideas include:

- Visual flicker and visual narrowing of road lanes created by use of forgiving obstacles

- Reduced lengths and spacing of centre lines are used when speed limit is low. See figure 4.1. The purpose is to influence speed behaviour by changing the frequency of lines meeting the drivers´ visual perspective. The suggested combinations of lengths and spacing of edge lines depending on speed limits are as follow:

  80 km/h: 5m – 10m – 5m – 10m – 5m -
  70 km/h: 4m – 8m – 4m – 8m – 4m -
  60 km/h: 3m – 6m – 3m – 6m – 3m -
  50 km/h: 2.5m – 5m – 2.5m – 5m – 2.5m -

  The same principles are used for edge lines as described in chapter 6.

- Rocking and waving road surface on selected road sections. See figure 4.2. The purpose is to arouse the attention of drivers by temporary decreasing the high level of driving comfort - especially in new cars.

- Markings painted to appear three dimensional are based on the idea that a “visual level of difference” probably effect drivers´ choice of speed in the same way as a “physical level of difference”. See figure 4.3.

- Rumbling road surface along edge lines and centre lines. See figure 4.4. Suggested width of vehicle lane depend on speed limit as follow:

40km/h	2.50m
50km/h	2.75m
60km/h	3.00m
70km/h	3.25m

  The width of vehicle lane is decreased by increasing the width of rumbling surface.
  On road sections where speed limits decrease from one level to another the width of rumbling road surface is changed gradually forming a funnel.

- Different new combinations of measures for speed impact

Some of the ideas already implemented for testing and evaluation are described below.

5. MARKINGS ALONG CENTRE LINES

Markings along the centre line of a regional rural road in the Danish County of South Jutland were established in late autumn 2003. ADT is 10.000 vehicles and 9-14 % heavy vehicles. Two different designs have been implemented for testing. Design A (see figure 5.1a) have been implemented on a 2.3km test section and design B (see figure 5.1b) have been implemented on another 2.5km test section.

The width of the marked central area is 1m. The distance between the green transverse strips is 0.60m. The length of the white longitudinal central lines is 5m and the spacing is 10m. It is allowed for cars to drive across the central marking and overtaking is still permitted. The marking is supposed to affect the driver visually but it is also audible when cars are crossing over. The purpose has been to reduce the number of head-on collisions by use of a low cost measure.

The first evaluation activities have been carried out by the county. Speed registrations show that mean speed and 85%-fractiles for speed are almost unchanged with a decrease on 1-2 km/h. More than 80 % of the interviewed give the correct answer that it is permitted to take over on the test section and cross the central marking while 13 % think that it is not permitted. About 20 % of the interviewed say that they do not overtake until they have

passed the test section. Observations on-site seem to show a smaller frequency of overtaking on the test sections compared to the adjacent road sections. 85 % of the interviewed road users express satisfaction with the new markings. Among the interviewed having a priority most of them prefer design A. If the new markings along the centre lines have the intended effect on head-on collisions is not known yet.

The test period runs until October 2007. The test sections will be evaluated in 2005 followed by a before/after-accident analyse in 2006/2007.

6. INTRODUCTION OF "2 – 1"- CROSS SECTION PROFILE

During winter 2003/2004 a 6km long section of a two-lane municipality rural road (Gurrevej) was redesigned by introduction of a new "2-1"(two minus one) cross section profile. See figure 6.1.

The new "2-1"- profile have only one central driving lane – 3.5m width – marked by 0.30m wide intermittent edge lines leaving an area of 0,85m width in both sides for cyclists and for cars to use in meeting situations. The length and spacing of the intermittent edge lines are longer the higher speed limit:

60km/h sections	2m – 2m – 2m – 2m –
50km/h sections	1m – 1m – 1m – 1m –
40km/h sections	½ m - ½ m - ½ m - ½ m –

Road width before varied between 5.0m – 6.5m. The road is a bit curvy. ADT is 2500 vehicles with 8-10 % trucks/busses. The new-profiled road is divided in three road sections with signed speed limits on 40km/h, 50km/h and 60km/h.

The new "2-1"- profile is supplemented by 12 speed reducers - designed as narrowing (16m long) edged by side islands. See figure 6.2. On a few spots where sight distance is too short for the "2-1"-solution the profile has remained as a two lane rural road. See figure 6.3.

Registration of road user behaviour is carried out during autumn 2004. The evaluations include studies of:

- Speed
- Driver behaviour in meeting situations on road sections with signed speed limits of 40, 50 and 60km/h.
- Driver behaviour in meeting situations at speed reducers
- Driver behaviour in transition zone between "2-1"-profile to ordinary two-lane cross profile marked by centre lines.
- Driver behaviour at intersections
- Citizens and road users opinions - interviews

The first evaluation results show:

- Speed limits are still exceeded and mean speeds are still too high compared to the signed speed limits. Mean speed is 60 km/h to 65 km/h and 85%fractiles are 69 km/h to 76 km/h on sections with signed speed limit 50 km/h after implementation of the new profile. Mean speed is 53 km/h to 57 km/h and 85%fractiles are 63 km/h to 68 km/h on the section with signed speed limit 40 km/h after the implementation. Mean speed is 69 km/h to 70 km/h and 85%fractiles are 78 km/h to 81 km/h on the section with signed speed limit 60 km/h after implementation of the new profile.
- The drivers seem to behave as intended in meeting situations on road sections: drivers give way by changing the lateral position to the right and in some cases the right wheels are crossing the intermittent edge line as intended.
- Mostly the meeting situations at speed reducers are handled without problems. The drivers seem to interact and adapt speed when approaching a narrowing letting the first arrival pass first. Problems are observed though in 5-10 % of the observed situations. It is not always quite clear to the drivers who should be the first to pass the narrowing. In some cases both drivers stop and wait for each other to pass. In other cases one of the drivers continue without slowing down "forcing" the other driver to give way. Accidents have occurred. The conclusion is already quite clear: It is necessary to add a sign to the narrowing to make it clear for all drivers who should go first.

- No conflicts have been observed in the transition zones where road profile changes from "2-1" to the ordinary two-lane cross profile. Drivers seem to follow the road markings as intended.
- At intersections drivers still stop at the stop line as intended. The apprehension for drivers not to stop before reaching the intermittent edge line on the crossing road seems to be unfounded.

The evaluation of road user behaviour will be finished during 2004/2005 followed by a before/after-accident analyse in 2006/2007.

7. ELECTRONIC DEVICES ON RURAL ROAD

Esrumvej - a rural county road – has been provided with a minor IT-system based on traffic detection connected to variable message signs at curves and intersections.

Curves
Speed detection has been connected to illumination of a warning sign located about 150 meters before entering the dangerous horizontal curves. If the drivers do not manage to slow down right in time before entering the curves the chevron signs along the curves will illuminate as an extra warning to the drivers. See figure 7.1.

Intersections
In two intersections on the test route approaching road users on the side roads are detected. The traffic detection is connected to an electronic warning sign located on the main road. If approaching road users are present on the side roads the warning sign will illuminate to warn the road user on the main road to be aware of crossing traffic. See figure 7.2. In one case the warning sign include a temporary speed reduction. See figure 7.3.

Evaluation
The pre-evaluation has been made by the local road authority shortly after opening in spring 2004. The preliminary experiences are positive. An evaluation will be carried out during 2005 followed by a before/after-accident analyse in 2006/2007.

8. PHYSICAL DIVIDERS ALONG CENTRE LINES ON RURAL ROADS

The main safety problem on two-lane rural roads concern "head-on"-collisions and single accidents. This is the reason for implementing physical dividers along the centre lines at two rural test routes in the County of Northern Jutland. Different designs of dividers have been described and considered (5). Some of them have been selected for testing.

The variations of main categories of ideas include a marked 1-2m wide central area along the road
- supplied with reflectors or transverse rumble strips along the center line of the road
- combined by vertical obstacles along the center line
- filled with grass or low vegetation and eventually combined with small islands in between
- supplied with crash barriers
- combined with a vertical displaced central island of a kind

The main categories mentioned can all be varied by using different materials, collared marking/road surface and adding sinking street lamps.

During 2004 physical dividers are implemented on two test routes:
a) A red colored central area along a rural regional road has been implemented. The central area is flanked by sinking street lamps on selected sections and by reflectors on the rest. Small central islands have been added on sections going through a small town. See figure 8.1 and figure 8.2.
b) A 2+1 road has been changed into a two-lane rural road with a central area along the road supplied with crash barriers.

The two test routes are going to be evaluated during 2005 followed by an accident analysis after three years.

9. THE FUTURE - CONCLUSIONAL REMARKS

With the aim to develop tools for speed adaptation in rural areas the implemented ideas from the catalogue mentioned above will be evaluated and more pilot studies for testing new ideas and new combinations of known elements are expected to be carried out during the next years. The results and experiences from the different test studies will lead to a new set up of recommendations and development of a new Danish guideline for speed management on rural roads.

REFERENCES

1. Danish Road Directorate. Hastighedstilpasning I åbent land – Idé katalog. Copenhagen. December 2003. http://www.vejregler.dk/pls/vrdad/vr_frame.f_index

2. Herrstedt, L.: Trafikanters Hastighedsadfærd – grundlæggende principper. Appendix til Ide katalog. Januar 2003. http://www.vejregler.dk/pls/vrdad/vr_frame.f_index

3. Herrstedt, L.: Making our Roads Safer – A Vision for the Future Safe Infrastructure. 1st Annual European Energy and Transport Conference. Barcelona. October 2001

4. Herrstedt, L.; Andersson, P.: Erfaringer med hastighedsdæmpning i danske kommuner. Vejdirektoratet. 2004. http://www.vejregler.dk/pls/vrdad/vr_frame.f_index

5. Nordjyllands Amt: Idéoplæg til fysisk midteradskillelse på landevej I åbent land. Oktober 2002.

6. Vejdirektoratet: Hastighed og Ulykker. November 2003. http://www.vejsektoren.dk/wimpdoc.asp?page=document&objno=6215

7. Vejdirektoratet: Uheld på veje I åbent land. Rapport 174.1998.

8. Havarikommissionen for Vejtrafikulykker: Rapport 1, 2002. og Rapport 2, 2003.

9. Elvik, R.; Mysen, A. B.; Vaa, T.: Trafiksikkerhetshåndbok. TÖI.1997.

10. Vejdirektoratet: Hastigheder 1999 – 2002. Rapport 284.2004

LIST OF FIGURES

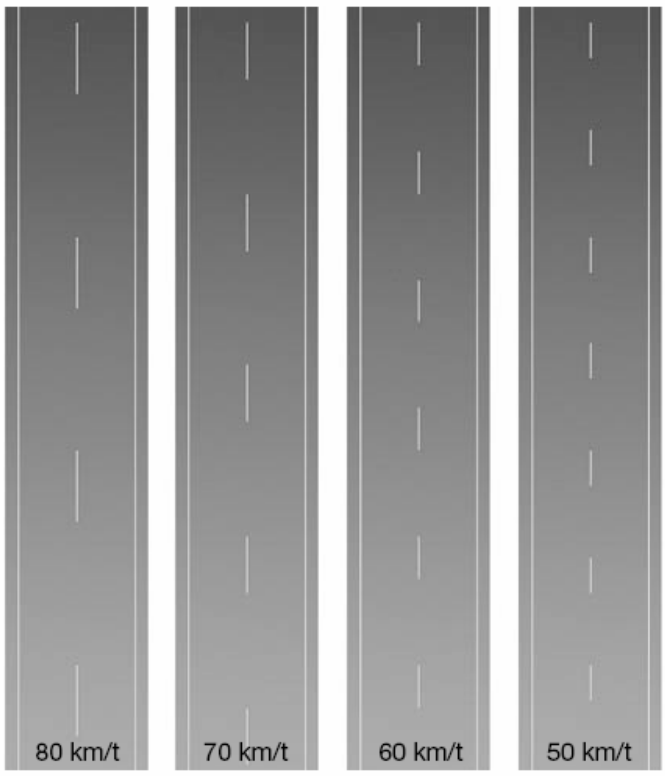

Figure 4.1: Length and spacing of centre lines depends on speed limit

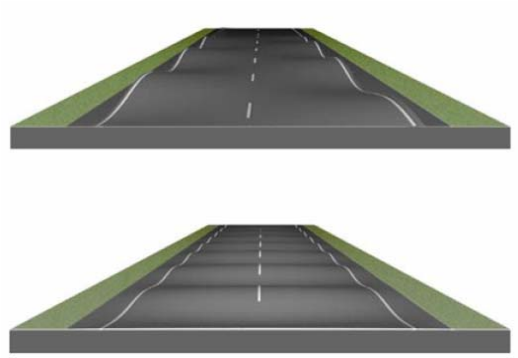

Figure 4.2: Rocking and waving road surfaces

Figure 4.3: Three-dimensional markings

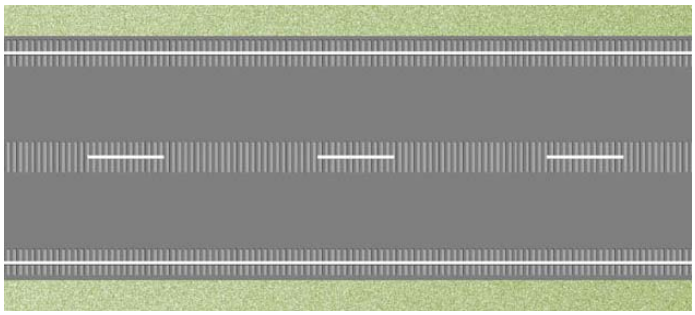

Figure 4.4: Rumble road surface along centre line and edge lines
The width of vehicle lane decrease with decreasing speed limit by increasing the width of the rumbling surface.

Figure 5.1a: Centre line marking – design A.

Figure 5.1b: Centre line marking – design B

Figure 6.1:”2-1”- cross profile with one central driving lane

Figure 6.2: Speed reducer designed as narrowing with only one central vehicle lane

Figure 6.3: Transition from”2-1”rural road to the ordinary two-lane rural road with centre line ahead

Figure 7.1: Chevrons in dangerous curves illuminate if speed is too high

Figure 7.3: VMS sign showing temporary speed limit and warning for crossing traffic ahead.

Figure 7.2: Warning sign showing crossing traffic in the intersection ahead

Figure 8.1: Red colored central area flanked by reflectors.

Figure 8.2: Small central islands have been added on sections going through the small town Harken.