

EVALUATION OF A SPEED ALERT SYSTEM ON CURVES BY RAINY WEATHER

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Introduction

In this paper, we present a new information system to alert users of an excessive speed according to weather conditions.

Inappropriate operating speed is a stubborn road safety issue. A degradation of atmospheric conditions can have dramatic consequences on drivers' safety. Indeed, vehicle handling can be difficult, even impossible, when the roadway is slippery. The situation is even worse when the driver is surprised because the road is usually without risk.

The system presented in this paper informs drivers of low skid-resistance conditions and warns them of an excessive speed towards these conditions.

The first part of this paper presents the proposed information system. The second part defines the risk function for maximum permissible speed in the curve. The third part analyses the system impact on operating speeds for free vehicles, and the last one its effect on headways between vehicles driving in platoons.

1. Information system

The proposed information system is presented in the figure 1. It is composed of two variable message signs, both being controlled by a datalogger. Two operating modes are defined:

- A **“general” alert** that triggers the first sign when the road surface is wet, i.e. the water depth on the road surface is greater than 0.05 millimeters. All users are affected by this first message.
- An **“individual” alert** triggered by an excessive speed regarding skid resistance conditions. In this mode, the second sign gives an alert for road users whose speed was detected as presenting a risk compared with a specific situation. An empirical function has been defined (presented in the next parts of this paper) to calculate a permissible speed in a curve as a function of road geometry and surface characteristics and water thickness. The function parameters are locally adjusted to give an alert for 15% of road users.



Figure 1: illustration of the information system in curve (above the site without the alert system, bottom the alert system)

The impact of the proposed alert system on driver behaviour was evaluated on a secondary road (RD 786) located in the vicinity of the city of Binic (Brittany, France). The Binic site has been instrumented with four speed sensors, a weather station and a sensor measuring water depths (see figure 2). The position of the inductive loops is given in the figure 3.

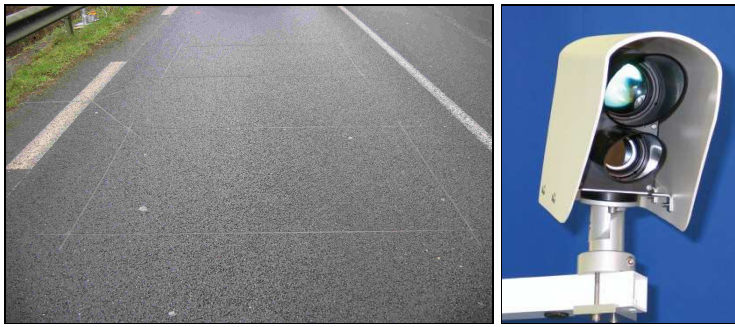


Figure 2: instrumentation (on the left, inductive loops, on the right, water depth sensor)

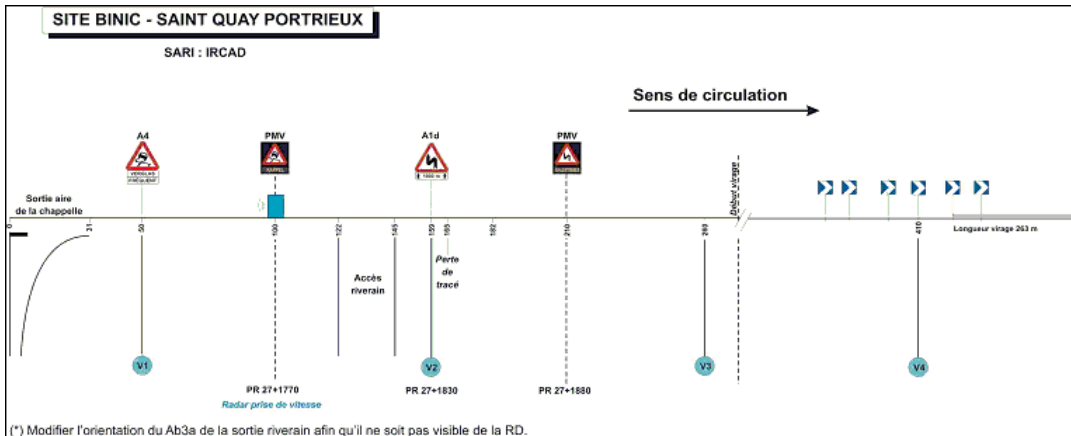


Figure 3: Binic site configuration and position of inductive loops

2. Maximum permissible speed and risk function

In this part, we present the calculation of the maximum permissible speed that is used to trigger the second sign. The principle is represented in the figure 4.

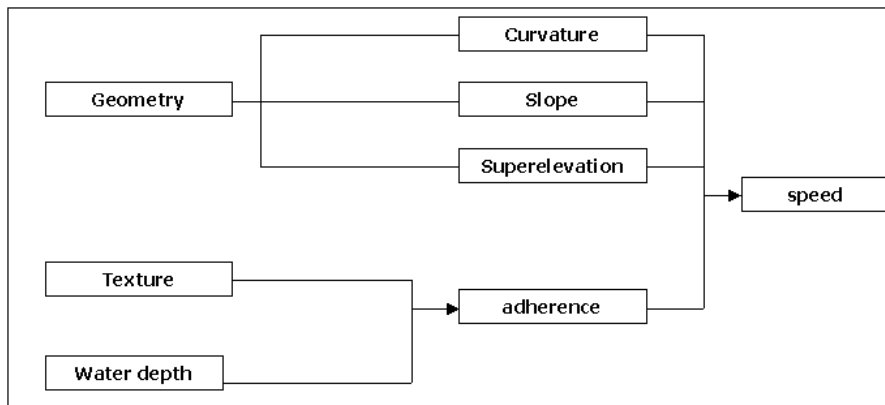


Figure 4: principle used to calculate the permissible speed

A vehicle does not slip on a curve if the friction force overcomes the centrifugal force, which is linked to the square of the speed. The following formula gives, for "average" drivers and vehicles, the maximum excessive speed V_{max} which depends on the transversal friction coefficient (τ), the curvature radius (R), the superelevation (s_l) and the gravity (g):

$$V_{max} = \sqrt{(\tau + s_l) \cdot g \cdot R} \quad (1)$$

with the correct units

However, five factors imply a decrease of that speed:

a) The water depth decreases the friction. The actual friction coefficient $\tau(h)$ is modulated by the water depth (h) according to the following formula [1]:

$$\tau(h) = -0.081 \cdot \ln(h) + \tau_0 - 0.05 \quad (2)$$

where τ_0 : friction coefficient measured at a conventional water depth of 0.5 mm.

b) The water depth (h) is measured on a flat area, but as the superelevation favours the water flow, the water depth on the curve (h_b) is smaller. Experimental measures show that h_b is obtained by dividing h by the coefficient 2.62 (at Binic).

c) A safety margin is necessary for a common driver, with a common vehicle. From experimental measures, Gallenne et al. [2] proposed to use only the third of the transversal friction coefficient, so the permissible speed V_p is:

$$V_p = \sqrt{\left(\frac{\tau(h_b)}{3} + s_l\right) \cdot g \cdot R} \quad (3)$$

Replacing the safe margin "3" by the effective margin c_i respected by the driver i , the reciprocal relationships between the effective margin and the speed are:

$$V_i = \sqrt{\left(\frac{\tau(h_b)}{c_i} + s_l\right) \cdot g \cdot R} \quad (4)$$

and the reverse formula:

$$c_i = \tau(h_b) / \left(\frac{V_i^2}{g \cdot R} - s_l\right) \quad (5)$$

Adding the index of the sensor, as the sensor located in the curve is the 4th one, the unsafe drivers are those such $c_i^4 \leq 3$.

d) The speed warning is delivered upstream the curve, so that the drivers will react before the curve. Let j_0 be the upstream sensor near the location of the radar controlling the speed warning. At j_0 , drivers are not yet concerned by the curve. An assumption that the unsafe drivers in the curve (in proportion u) are already the less safe ones at j_0 , allows identifying these drivers at j_0 : those whose speed at j_0 is greater than the empirical percentile of the speed at j_0 for the water height h , $V_u^{j_0}(h)$, or those whose effective margin $c_i^{j_0}$ is less than the empirical percentile $C_u^{j_0}$

of the $c_i^{j_0}$ distribution. Note that, due to the number of data, the confidence in a single value $C_u^{j_0}$ (independent of the water depth) is greater than in a vector $V_u^{j_0}(h)$; it is also easier to store and use in real time.

e) It was decided, in order to make possible the comparison of driver's responses, to address the 15% of drivers instead of addressing all unsafe drivers.

So from the reference phase data, the coefficient c_i^{j0} for each driver i have been computed, then sorted, and the 15% percentile $C_{15\%}^{j0}$ has been established.

In the real time, the coefficient c_i^{j0} for each driver at sensor j_0 is computed, compared with $C_{15\%}^{j0}$. When $c_i^{j0} \leq C_{15\%}^{j0}$, the speed warning is switched on.

The values of the margin coefficient obtained during the reference phase are the following:

	Binic	
	$C_{15\%}^{j, Binic}$	$C_{safe}^{j, Binic} = C_{21.6\%}^{j, Binic}$
% addressed vehicles	15%	21.6%
Percentile Sensor 1	2.22	2.63
Sensor 2	1.87	2.10
Sensor 3	2.22	2.47
Sensor 4		3.0 (definition)

Safety margin: Safe percentile and 15% percentile at the different sensors

At Binic, the use of the margin $C_{15\%}^{2, Binic}$ succeeded in addressing a percentage of drivers near 15% (whatever the water height was, provided it was higher than 0.05mm).

3. Assessment on free vehicles

The main objectives of the evaluation are to qualify and quantify the impact of information systems deployed on the Binic experimental site during periods of activation of signs by considering different stages of activation. We only consider free vehicles. A vehicle is said to be free if its headway with the preceding vehicle is more than 5 seconds.

The three stages considered for the evaluation are following:

- **The reference stage:** during this step no sign is set up and drivers' speed have been analysed to have a reference in order to quantify the alert system impact.
- **The general alert stage:** during this step, we measure the impact of the first sign lighting on approaching speeds before and in the curve. These speeds are compared to those of the reference stage.
- **The individual alert stage:** during this step, we measure the impact of the second sign lighting on approaching speeds before and in the curve. These speeds are compared to these of the reference stage for drivers who should have been alerted.

Two indicators have been used: V_{50} and V_{85} speeds, which are respectively the 50th and 85th percentiles of the speed distribution of free vehicles.

Figure 5 presents speed results for the reference stage.

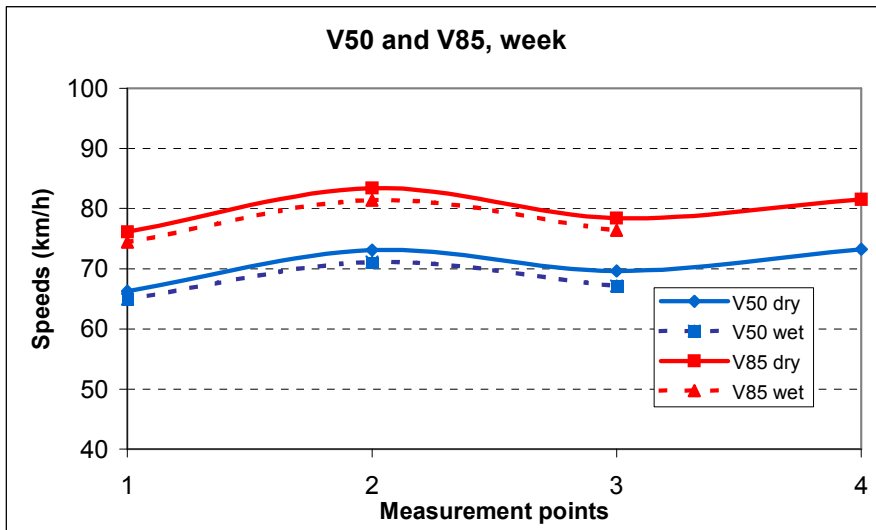


Figure 5: speeds results for the reference stage

There is no real curve effect that led users to significantly reduce their speed when crossing the curve. Depending on traffic conditions, this effect is between -5 and -1 km/h for the V_{85} . These main results confirm previous studies [5] especially about night period. The low visibility due to the rain and the night has the greatest impact on speed.

Figure 6 presents speed results for the general alert stage.

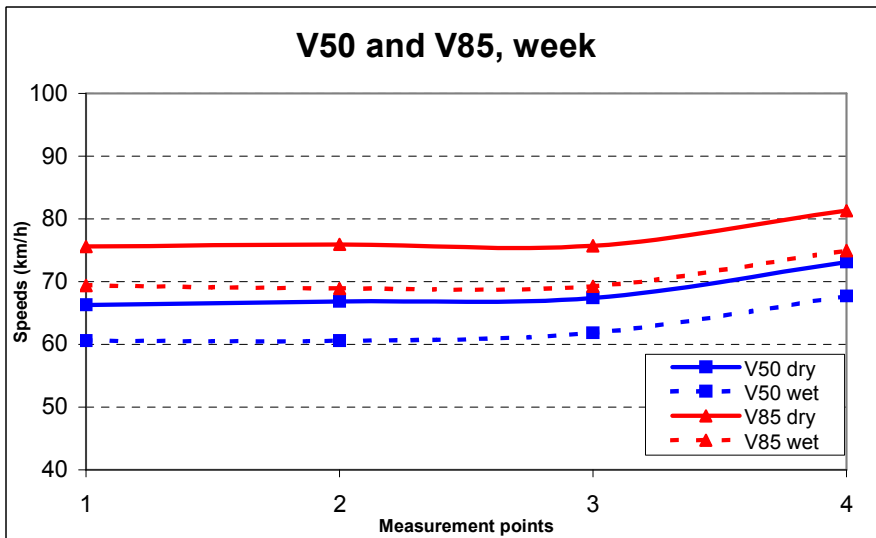


Figure 6: speeds results for the general alert stage

If we look at differences in driving speeds depending on the road surface condition (dry or wet), it appears the following trend: in all measurement points, there was a greater reduction in speeds in the condition "wet road" when the first sign is activated. Reasoning on the indicator V_{85} , the table below illustrates this by describing the difference in V_{85} expressed in km/h for situations Dry vs Wet for both phases (Reference vs General alert).

Table 1. impact of the first warning sign on whole instrumented area

Traffic	Stage	Speed 1	Speed 2	Speed 3	Speed 4
Night	Reference	-4	-5	-5	
	General Alert	-9	-9	-10	-8
Day	Reference	-2	-2	-2	
	General Alert	-7	-7	-7	-6

The table 1 shows the impact of the warning signs on the whole instrumented area. It should be noted that the sign is actually visible upstream of the first point of measurement.

The impact results in a higher decrease of driving speeds in the condition "wet road". This reduction is generally about 5 km/h, and can reach 7km/h. Therefore, comparing the same conditions of pavement surface for the reference and the general alert stages, it can be said that speeds are lower in this second phase.

The speed reduction for wet road condition can be considered as a positive impact of the warning message sign.

Because of the site configuration and the instrumentation used, the same analyse cannot be done for the individual alert. The hypothesis is that the alerted road users reduce the speed more than the non-alerted road users by considering the initial speed. The main difficulty is to separate two populations:

- General alert: should have been alerted drivers vs. non-alerted drivers
- Individual alert: alerted drivers vs. non-alerted drivers

So we calculate the difference speed between measurement points 1 and 3. The AG column gives the speeds difference during the general alert and the AI column gives the speeds difference between the individual alert. If the alerted road users reduce more their speed than non-alerted, the "evolution" value should be greater for the higher percentiles (alerted drivers). Results are presented on the table below

Table 2. impact of the second warning sign

V1-V3 Centiles	H2o : 0.05 - 0.09 mm			H2o : 0.10 - 0.19 mm			H2o : 0.20 - 0.39 mm		
	AG	AI	Evolution	AG	AI	Evolution	AG	AI	Evolution
5%	-16	-10	-6	-16	-8	-8	-17	-9	-8
10%	-7	-4	-3	-7	-3	-4	-7	-5	-2
15%	-6	-4	-2	-6	-4	-2	-5	-4	-1
20%	-5	-3	-2	-4	-4	0	-5	-4	-1
25%	-4	-3	-1	-4	-2	-2	-4	-3	-1
30%	-4	-2	-2	-3	-3	0	-4	-3	-1
35%	-3	-2	-1	-4	-3	-1	-4	-3	-1
40%	-4	-3	-1	-3	-2	-1	-3	-2	-1
45%	-3	-2	-1	-3	-2	-1	-2	-2	0
50%	-3	-2	-1	-2	-2	0	-2	-3	1
55%	-3	-1	-2	-2	-2	0	-2	-1	-1
60%	-3	-1	-2	-2	-2	0	-2	-1	-1
65%	-3	-1	-2	-1	-1	0	-2	-2	0
70%	-3	-1	-2	-1	-1	0	-2	-1	-1
75%	-2	0	-2	-1	0	-1	-3	-1	-2
80%	-3	-1	-2	0	-1	1	-2	-1	-1
85%	-3	0	-3	0	1	-1	-2	-1	-1
90%	-2	-1	-1	0	0	0	-1	-1	0
95%	-2	0	-2	0	1	-1	-2	0	-2
100%	8	3	5	3	-1	4	-4	4	-8

Table caption

	Drivers not alerted
	Drivers probably alerted
	Drivers surely alerted

Speed measurements before and 50m after the second sign that displays individual warning information do not show a real impact by an effect of reducing speeds for the part of the drivers submitted to the alert message compared with drivers who had not been alerted. However this does not mean that the alert message does not impact on user behavior. It must however be assessed using other methods or by adapting the one implemented in this project by accessing to individual trajectories.

4. Assessment on vehicles driving within platoons

As a part of this research, risk indicators built from headways and speeds for vehicles driving within platoons have been studied. The idea was to test if a speed alert system could have an impact, positive or negative, on headways, and then on rear-end collision risk.

It has been considered that to be in a same platoon, the time gap between two vehicles should be less than 4 s. This value results from a previous study [3], and is consistent with the threshold used to define a free vehicle in the previous part of this paper, which should be equal or higher.

Rather than the classical time to collision (ttc), the risk indicator chosen here is the time gap to speed ratio (tgsr). As the sensor signal is delivered at the rear of the vehicles, and if V_i , L_i and t_i denote respectively the speed, the length and the time of passage of the i th vehicle, the indicators relative to two following vehicles numbered $i-1$ and i express as:

$h = t_i - t_{i-1}$	headway
$tg = h - (L_i / V_i)$	time gap
$ttc = tg \cdot V_{i-1} / (V_i - V_{i-1})$	time to collision
$tgsr = tg / V_i$	time gap to speed ratio

With such an indicator as tgsr, the less is its value and the more is the risk. It can be defined for it a "mandatory" threshold being the ratio of the minimum time gap (2 s) to the speed limit

(90 km/h), i.e. $0.08 \text{ s}^2/\text{m}$. As in the previous study, it has also been computed the proportions of t_g and t_{tc} lesser than given thresholds.

The effect of two factors on this risk indicator has been observed: a wet pavement (water depth greater than 0.05 mm) and a speed warning sign. Concerning the speed warning sign, the three abovementioned stages have been compared.

The only clear result, which confirms what had already been noted in the previous study, is that a wet pavement has an effect on the risk indicator. The cumulative distribution of t_{gsr} is then shifted to the right, i.e. drivers are more cautious, whether the station where it is computed. However, this does not imply that this higher caution is enough to compensate the lesser skid resistance. A further study should be undertaken about this point for a better insight.

But the effect of the speed alert system is not clear, sometimes corresponding to a slight increase in caution, sometimes to a slight decrease, depending on the measurement point. Furthermore, conditions which should lead to similar results (e.g. general alert and individual alert without activation of the individual speed alert display) may lead to slightly different results, also depending on the measurement point.

As the differences were slight and not consistent, it has then been considered that it could not be attributed any noticeable effect of the speed alert system on the rear-end collision risk indicator. More detailed results are given in the full report [4].

Conclusions

In this paper, we have presented a new alert system to inform drivers of a risk of grip loss. The assessment has been carried out by comparing drivers' speed during three steps: a reference stage, a general alert and a individual alert [6].

We showed that the first sign has a positive effect. This effect is reflected by lower driving speeds (more important in the situation "wet road") during which the sign is activated. Thus, it appears that the speed reduction during this phase is increased by 5 km/h compared with the same conditions of the reference phase. This observation is made for all points of speed measurements. Assessing the impact of individual alert message has not demonstrated a significant reduction in driving speeds for the part of drivers who has been warned against that which has not been.

A complementary study on vehicles driving within platoons showed that it could not be attributed any noticeable effect of the speed alert system on the rear-end collision risk indicator.

A complementary study (in progress) tries to understand why alerted road users don't reduce more speed by addressing attitude and behaviour. For that, individual trajectories are observed and drivers are questioned just after the curve.

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