DYNAMIC SPEED ADAPTATION IN ADVERSE CONDITIONS

– A System Proposal –

András VÁRHELYI
Department of Technology and Society, Lund University
Lund, Sweden

(Received May 27, 2002)

This paper proposes a system for dynamic speed adaptation in adverse conditions, such as wet/slippery roads, decreased visibility, darkness and sharp curves. Accident risks increase drastically in such conditions, especially since drivers often do not adapt speeds to lower friction or impaired visibility. Thus, the discussion is centred around a method for calculating the appropriate highest speeds and a system to influence driver's speed-choice in these conditions via an in-vehicle device. The safety effect of the proposed system is estimated to result in a 19%–42% reduction of injury accidents in Sweden. The paper concludes by making suggestions for further research into alternative technological solutions, effects on driver behaviour and workload and implementation of the system for reasons other than weather and road-dependent adverse conditions.

Key Words: Dynamic speed adaptation, Friction, Visibility, Darkness, Curves, Appropriate highest speed

1. INTRODUCTION

Accident risks increase drastically in adverse conditions (wet/slippery roads, darkness), especially since drivers often do not adapt speeds to lower friction or impaired visibility. The accident risk on wet roads is up to 1.5 times[1] and on slippery roads up to 9 times[2] higher than on dry road surfaces. In darkness it is up to 2 times higher than in daylight[3]. The relationship between the speed level and accident risk is well established[4–6], making it clear that speed adaptation in critical conditions is unsatisfactory and that the safety potential of appropriate speeds in these conditions is high.

Traditional measures to influence speed have been proven time and again to be insufficient. The speed limit system, enforcement and engineering measures are rigid elements trying to work in a dynamic system[7]. A potentially more successful alternative would be one which influences the driver's speed choice with in-vehicle devices. Information technology offers the means to realise this option with the help of the concept of "Intelligent Speed Adaptation" (ISA). ISA concerns speed adaptation to actual speed limits and is already being tested on a large scale in Sweden, the Netherlands and the UK, and trials are being started in other European countries.

In the process of developing a system for dynamic speed adaptation in adverse conditions a few questions have to be answered: 1) What are the situations where the driver underestimates the accident risks and consequently fails to choose the appropriate speed?, 2) What are the appropriate highest speeds in these critical situations?, 3) How should a system for dynamic speed adaptation be designed?, 4) What technical solutions are feasible?, 5) What is the acceptance level?, 6) What are the safety effects and other implications?

2. CRITICAL CONDITIONS

In order to identify critical conditions and situations in which badly adapted speeds contribute to traffic "unsafety", all the conceivable situations were systemized and compiled in taxonomy[8]. In one dimension, the situations were place-dependent, e.g., road type, intersections or other specific locations. In a second dimension, the situations depended on conditions changing with time, such as critical road surface, visibility and weather conditions. A third dimension was defined by interactions with other road-users, which generated a certain accident potential. These three dimensions covered a large number of potentially critical situations, which were brought together in a matrix. The severity of the situations was estimated in an expert survey by 45 traffic safety researchers from 19 countries. The experts were asked to rate the situations according to the extent to which they felt that inappropriate speeds played a significant role in creating accident risks in the situations. The results showed that the following situations were ranked highly: 1) road surface, visibility and weather-dependent situations; 2) place-dependent situations, where drivers, after prolonged driving at high speeds, had to reduce the speed to a lower level to be able to negotiate the situation (such as motorway exits and sharp bends); 3) interactive situations with other road-users.

The Swedish accident statistics[9] indicated the following shares of injury accidents reported to the police: 1) 26% in darkness; 25% on wet roads; 16% on icy/snowy roads; 10% in rain; 6% in falling snow; 3% in haze/fog. However, some of these situations often occur at the same time (e.g., slippery road and darkness), and there is some overlapping in the accident figures. 2) Motorway exits: about 1%; There is no available data for accidents on sharp bends. 3) Encounters between motor vehicles with crossing course: 13%; between motor vehicles and pedestrians: 7%. These observations imply that improved speed adaptation in these situations has a large safety potential. The scope of this paper, however, is limited to the first two dimensions.

3. APPROPRIATE HIGHEST SPEEDS

For each situation there is a maximum speed value at which the driver can manage a given task. Such "appropriate highest speed" values can be calculated theoretically for every situation based on road friction, the slope of the road, visibility, curve radius and super-elevation. There are two plausible ways to calculate the appropriate speeds in adverse conditions. One is to calculate the average speed, which would give the same accident risk in adverse as in normal conditions, with the help of relationships estimating the ratio of injury accidents before and after speed changes according to Nilsson's[10] model. This method has several draw-backs: 1) The starting point is today's risk level in "normal" conditions at current average speeds, which are mostly over the speed limit, implying that these high average speeds with the corresponding higher accident risks are acceptable. 2) The output from this calculation would be the desired **average speed** in e.g., slippery road conditions, but these conditions have a wide range of friction values and in some cases the appropriate speed calculated in this way would be too low and in other cases too high. 3) The method is too abstract to be understood and accepted by the individual driver. The other method, chosen here, is based on the reasonable criterion that the driver must be able to stop the vehicle within the same distance whether on wet and slippery roads or dry roads, within the visibility distance, as well as keep the car on the road round sharp bends. The starting point for this method is the stopping distance in normal conditions and at the prevailing speed limit (presupposing that this is based on the road features) on a given road, which can be named the "constant stopping distance". The calculation of the appropriate highest speeds on the criterion of "constant stopping distance" means that the speed is determined from the prevailing friction, so that the vehicle can stop within the same distance regardless of whether the road surface is dry or wet/slippery. Using this method also means that the risk level at a speed equal to the speed limit is acceptable. Nevertheless, the speed limit should be adjusted to an acceptable risk level in normal conditions. Appropriate speeds, calculated according to this method, would not necessarily carry the same injury risks in adverse as in normal conditions, as lower speeds in adverse conditions would lead to less severe consequences in a collision.

The stopping distance is calculated according to the equation:

$$s = v * t_r + v^2/(2*g*(f+G)) \quad \text{.................................} \quad (1)$$

where s = the car's stopping distance (m);
v = the car's speed (m/s);
t_r = the driver's reaction time (2 sec);
g = acceleration due to gravity (m/s^2);
f = coefficient of braking friction (dry road: 0.5–0.8; wet road: 0.3–0.4; slippery road: 0.1–0.2);
G = gradient (slope of the road) tan α (+uphill; –downhill).

When v is solved from the equation, the speed (the solution with the positive sign) is obtained according to Equation 2:

$$v = (-t_r + \sqrt{t_r^2 + 2s/(g(f+G))})*(g(f+G)) \quad \text{..........} \quad (2)$$

3.1 Wet and slippery road conditions

Table 1 shows examples of constant stopping distances when the driver travels at the speed limit.

Figure 1 shows the appropriate highest speeds on wet and slippery roads, based on the "constant stopping

Table 1 Constant stopping distances at different reference speeds (the speed limit) on a horizontal road ($G=0$) with dry surface ($f=0.5$)

Reference speed (km/h)	10	20	30	40	50	60	70	80	90	100	110	120	130
Constant stopping distance (m)	6	14	24	35	47	62	77	95	114	134	156	180	205

distances” for various roads with dry surfaces when the driver travels at the speed limit. The speed level which gives the same stopping distance on both wet and dry roads is between 82 and 92% (depending on the friction value) of the speeds on dry roads. On slippery roads these are between 50 and 74% of the speeds on dry roads.

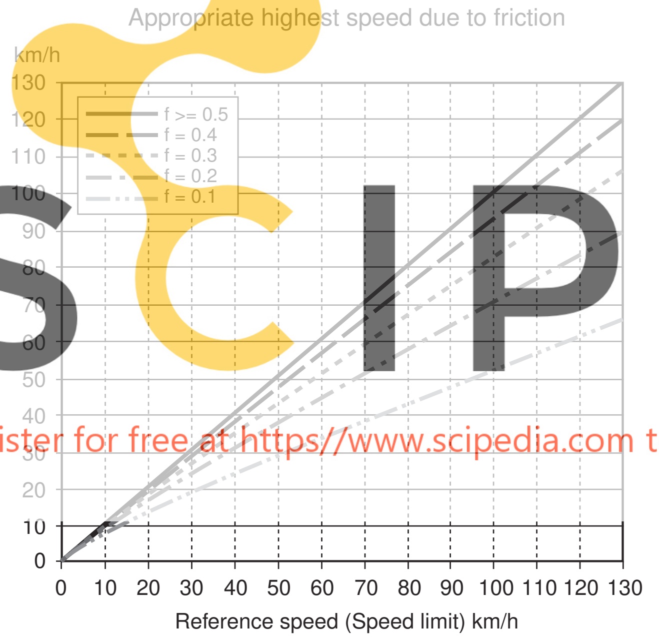

Fig. 1 Appropriate highest speeds on wet (0.2<f<0.5) and slippery (f<0.2) road surfaces based on “constant stopping distances” on a horizontal road (G=0)

3.2 Poor visibility

In conditions of haze, fog, rain or falling snow, according to the most stringent criterion, the stopping distance should be a maximum of half the visibility distance so that an oncoming vehicle, emerging unexpectedly on the wrong side of the road, can also stop in time if the risk of a collision arises. Equation 2 can be used to calculate the appropriate highest speed, where s = half the visibility distance. However, if a more lenient criterion is implemented, which prescribes that the driver has to be able to stop his vehicle in case of an unexpected stationary object ahead (the oncoming traffic factor is overlooked, which is obvious in the case of motorways), s = visibility distance in Equation 2. Figure 2 shows the appropriate highest speeds in reduced visibility for a number of combinations of visibility distance and friction values. In reduced visibility the visibility distance is decisive for the appropriate highest speed.

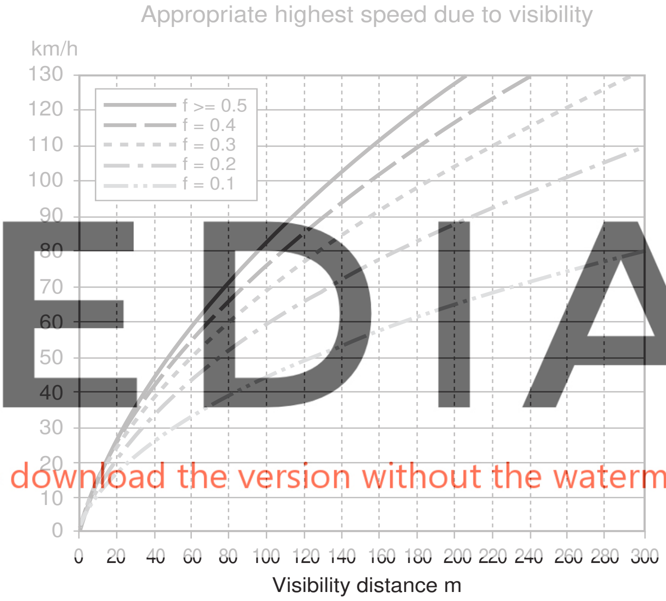

Fig. 2 Appropriate highest speeds (km/h) in reduced visibility (at which a vehicle can be stopped within the visibility distance)

3.3 Darkness

The criterion for the calculation of the appropriate highest speed in darkness is that the stopping distance must be shorter than the visibility distance for the vehicle to stop in case of an unexpected stationary object ahead. In darkness this very often means that the stopping distance on roads with oncoming traffic has to be shorter than the visibility distance lit by low beam headlights, which is about 50m. On roads without oncoming traffic and where there is no risk of being blinded by oncoming lights (motorways), the stopping distance has to be shorter than the visibility distance lit by high beam headlights, which is about 150m. The appropriate highest speeds in darkness are obtained by means of Equation 2 where the “lit-up visibility distance” replaces the “constant stopping distance”. Figure 3 shows the appropriate highest speeds on roads with different friction values and in darkness, based on the “lit-up visibility distance”.

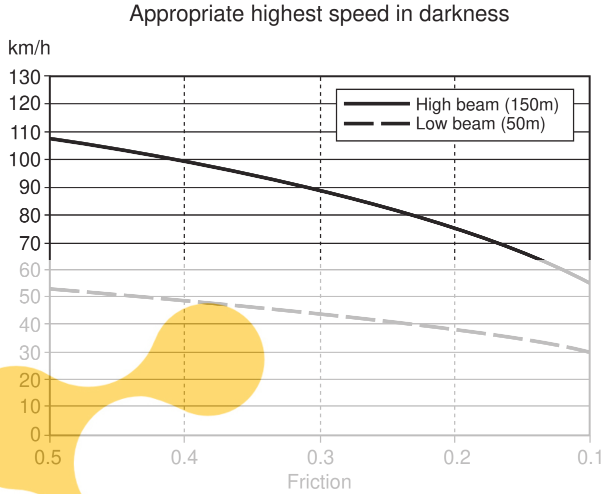

Fig. 3 Appropriate highest speeds (km/h) in darkness at which the vehicle can stop within the distance lit up by low beam headlights (50m) and high beam headlights (150m) on roads with different friction values

The speed in darkness and with low beam headlights should not exceed 60km/h on dry roads, 50km/h on wet roads and 40km/h on slippery roads. With high beam headlights these values are 110km/h on dry roads, 100km/h on wet roads and 80km/h on slippery roads. Some of the highest appropriate speed values with high beam headlights calculated in the table above are higher than the appropriate maximum speeds based on the “constant stopping distance” (in Figure 1). In such cases the lower value of the two (calculated on the two different criteria) should be chosen. When driving in darkness with low beam headlights at speed levels of 50km/h and below, the “constant stopping distance” is the decisive criterion for the appropriate highest speed. Over 50km/h, the criterion “lit-up visibility distance” is decisive. When driving with high beam headlights on roads with speed limits of 100km/h and below, “constant stopping distance” is decisive. At speed limits of 110km/h and over, the “lit-up visibility distance” with high beam headlights is shorter than the “constant stopping distance”, and therefore the former criterion is decisive for the appropriate highest speeds.

3.4 Sharp curves

The maximum speed at which a vehicle can be kept on the road while negotiating a curve can be calculated theoretically according to the equation[11]:

$$v = \sqrt{gR(e+f_s)} \quad \text{.......} \quad (3)$$

where g = acceleration due to gravity (m/s^2);
R = curve radius (m);
e = superelevation;
f_s = coefficient of side friction.

The maximum available side friction is about 75% of the braking friction. However, it is not appropriate to utilize the maximum available side friction as it would mean that the driver balances on the edge of being able to keep the vehicle on the road. It also causes side forces which can be very uncomfortable. The appropriate highest speed is then calculated on the basis of acceptable side friction. As the side friction decreases with increasing speed, at a speed level of 40km/h the acceptable side friction is about 60% of the maximum available, while at speeds of about 100km/h it is about 45%[12]. The relationship between acceptable side friction and braking friction for different speeds is represented by the following equation:

$$f_s = f((52 - 0.185v)/100) \quad \text{.......} \quad (4)$$

where f_s = coefficient of side friction;
f = coefficient of braking friction;
v = speed (m/s).

Figure 4 shows some examples of the appropriate highest speeds at which, theoretically, sharp curves with different radii can be safely and comfortably negotiated.

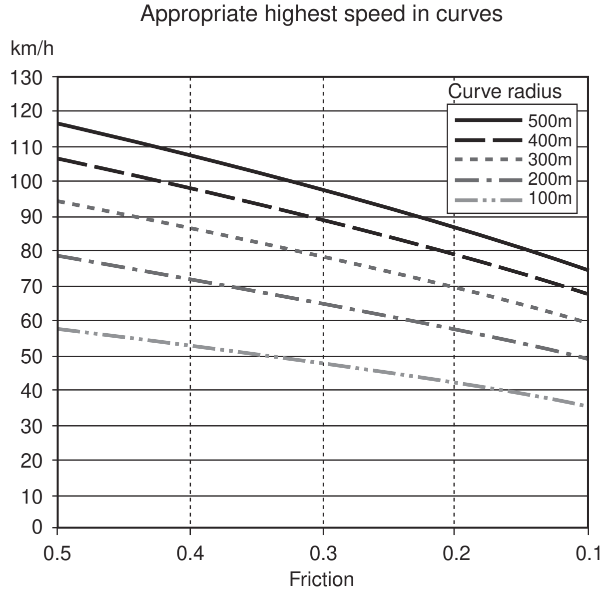

Fig. 4 Appropriate highest speeds (km/h) when negotiating curves with different radii and friction values (superelevation e = 0.055)

4. SYSTEM DESIGN

In the proposed system, speed adaptation to the actual conditions is achieved by activating the feed-back system at the appropriate highest speed. The road friction, visibility and light conditions are constantly monitored. Based on this on-line information, together with other relevant data (such as speed limit, gradient, curve radius, super-elevation), the appropriate highest speed is calculated. Information on the prevailing conditions and the appropriate highest speed is transmitted to individual vehicles. The driver is informed visually and/or audibly and given feed-back when the speed of the vehicle comes close to the appropriate highest speed.

4.1 Algorithm

The appropriate highest speed, according to the criteria in different critical conditions discussed above, is calculated by the system algorithm according to equations 2 and 3 (see Figure 5). These conditions are: 1) Speed limit. 2) Decreased visibility because of fog, haze, rain, snow. The inputs for this function are friction, gradient and visibility distance. 3) Darkness. The inputs for this function are friction, gradient and lit-up visibility distance (low beam / high beam). 4) Wet/slippery road with decreased friction. The inputs for this function are friction, gradient and “constant stopping distance”. 5) Sharp curves. The inputs are curve radius, superelevation and side friction. The output of the algorithm is the appropriate highest speed. Should there appear several critical conditions at the same time, the algorithm chooses the lowest speed value.

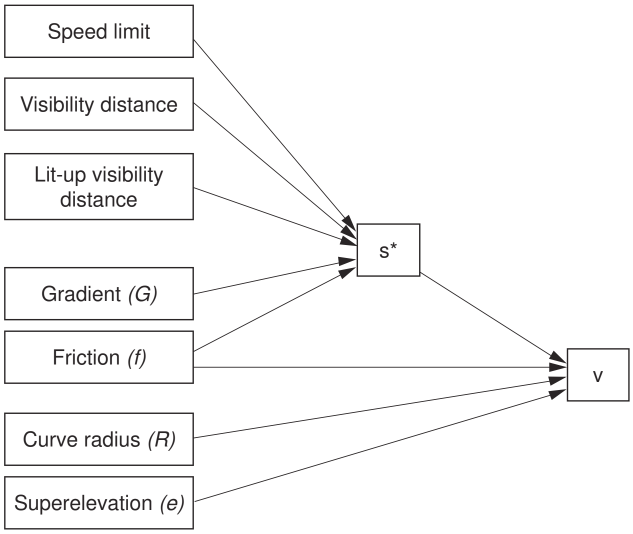

Fig. 5 System algorithm for calculation of the appropriate highest speed in different critical conditions and situations (s* = the lowest of “constant stopping distance”,“ visibility distance” and “ lit-up visibility distance”)

4.2 Technical solutions

The design of the human-machine interface of an in-vehicle driver assistance system is of utmost importance[13–16]. The system should facilitate the driver’s task and not increase his workload or produce any other disturbance. In the proposed system, the appropriate highest speed can continuously be displayed for the driver, which obviates the need to search for and recall information on speed limits. He does not have to concentrate on the speedometer as he has to in today’s system. When the appropriate highest speed changes, auditory information is given and the reason for the change is displayed. In order to get the driver to accept the lowered speed it is important that he is informed of the reason for it[17]. At the same time, the accelerator pedal’s counter-force gives feed-back when the speed comes close to the appropriate highest speed. This form of feed-back was found to be most effective in influencing of a driver’s speed choice[18].

Technology for the different parts of the proposed system is being developed and used in experiments. The basic component of the system is the active accelerator pedal, which is being used in several field trials. In an ongoing project in Lund, Sweden, 290 vehicles have been equipped with this kind of active accelerator pedal, digital maps containing all the speed limits, GPS and a navigation system. Road friction can be measured by e.g., using the difference in wheel velocities of driven and non-driven wheels. A test prototype of Slip-based Automatic Friction Evaluation has worked well in a test car[19]. Visibility range meters, which are primarily used in aerodromes, have been used in a fog warning system on motorways in Germany. However, this equipment is rather expensive. Nevertheless, there are emerging low-cost alternatives for use as vehicle-based visibility range meters. A Swedish company has developed a compact low cost sensor, which uses a backscatter technique to analyse water particles of different forms in the air. This mobile sensor can be installed in individual vehicles and has outputs for fog, rain and snow. Information to the vehicles can be transmitted via micro-waves, radio-waves, GSM systems with High Speed data or G-PRS or the coming G3 UMTS. The function of dynamic speed adaptation in darkness has to be complemented with a function monitoring the lit-up visibility distance, and preventing the driver from using high-beam headlights in case of oncoming traffic. The technology for this has to be developed.

5. ACCEPTANCE

When it comes to the introduction of in-car systems for driver assistance, user acceptance is of great importance. A nationwide survey of 1,000 Swedish driving licence holders showed that the majority of the respondents (60%) were positive to a device which automatically lowered the maximum possible speed of the car in slippery conditions and poor visibility[8]. Besides, acceptance is a process and not an unchangeable state. Different trials have found that acceptance increases after users have tried out such a device[20,21].

6. SAFETY EFFECTS

Empirical relationships can be used to estimate changes in the number of accidents following changes in speed levels. According to Nilsson[10], the following relations estimate approximately the ratio of injury accidents before and after the speed change:

(Injury acc. rate after) / (Injury acc. rate before) =
(mean speed after / mean speed before)^3 .... (5)

The assumed scenario corresponds to a situation where all vehicles are equipped with an active accelerator pedal and therefore do not exceed the prevailing speed limit. In the calculations of safety effects it is assumed that vehicle mileage remains unchanged after the introduction of the system. The calculation of the system's total effect on injury-accidents in Sweden is shown in Table 2.

The results show that the proposed speed adaptation system would lower the number of police-reported injury-accidents by between 19% and 34%. The calculation is "conservative" because it is based on **average** present speeds and **maximum** speeds in the dynamic system. It is unlikely that the average speed in such a system would reach the maximum allowed speed. Besides, it is assumed that the "unspecified" group of injury-accidents (20% of the total) are not affected. If these are also assumed to be affected to the same extent as under the estimable conditions, the total effect will be a reduction in police reported injury accidents by between 24% and 42%. The calculation does not include conditions such as impaired visibility due to fog, rain and falling snow due to the lack of present speed data in these conditions. Seventeen percent of the total number of injury-accidents occur in these conditions. It is difficult to estimate the effects of these functions as speed data and, in some cases, accident data are not available for these situation types. Even, if most of these conditions coincide with darkness and wet or slippery roads, the speed adaptation system in these situations represents a further safety potential. What is more, the effect should be even stronger since speed variance should be much lower in the system than presupposed in Nilsson's[10] model.

7. DISCUSSION, CONCLUSIONS

Dynamic speed adaptation is a powerful tool in road safety improvement. It has an unprecedented safety potential, it is feasible, the technology is available, and acceptance is reasonably good. The estimated safety effect of dynamic speed adaptation in conditions of lowered friction is a reduction in the total number of injury accidents by between 9 and 15% in Sweden. In conditions of poor visibility, it is not possible to calculate the safety effects of the system due to the lack of present speed data in these conditions. Some idea of the safety potential may be obtained from the fact that 17% of the total number of injury accidents reported to the police in Sweden, occur in rain, falling snow and fog. It is not possible to estimate the safety effect of dynamic speed adaptation along sharp bends either, as there is no present speed and accident data available for this situation in Sweden. The estimated safety effect of speed adaptation in darkness is a reduction in the total number of injury accidents in Sweden by between 8 and 16%. In addition to accident reductions, the system would change the social climate in traffic and make driving less stressful as pressure from other drivers to "follow the rhythm" would be more infrequent. More homogeneous speeds in the system should increase the level of service and minimize the number of overtakings. The system would help to eliminate the phenomenon of behaviour transfer when high speeds on high standard roads influence speeds on connecting low standard roads.

Dynamic speed adaptation will definitely not be the only IT-based system in traffic, and its effects will be

Table 2 Calculated effect of the proposed system for dynamic speed adaptation on injury-accidents in Sweden (v_p = Present average speeds; v_d = Maximum speeds in the system; P_p = Present number of injury accidents reported to the police; P_d = Number of predicted injury accidents in the system)

Road type/ condition			v_p km/h	v_d km/h	$(v_d/v_p)^3$	P_p	$P_d = (v_d/v_p)^3 * P_p$	Change in P number	Change in P (%)
50	daylight	dry	55	50	0.75	3,022	2,267	–755	–25%
70	day-light	dry	78 –86	70	0.54–0.72	1,474	796–1,061	–678/–413	–46%/–28%
		wet	78.5–80	58–65	0.38–0.57	566	215–323	–351/–243	–62%/–43%
		slip	71.5–73.5	38–50	0.14–0.34	282	39–96	–243/–186	–86%/–66%
	darkness	dry	80–88	52–70	0.21–0.67	300	63–201	–237/–99	–79%/–33%
90	day-light	dry	91–102	90	0.69–0.97	1,003	692–973	–311/–30	–31%/–3%
		wet	85–92	74–83	0.52–0.90	335	174–301	–161/–34	–48%/–10%
		slip	81.5–92	47–63	0.13–0.46	288	37–132	–251/–156	–87%/–54%
	darkness	dry	97.5–102.5	52–90	0.13–0.79	355	46–280	–309/–75	–87%/–21%
110	day-light	dry	99–106	110	1.12–1.37	129	144–177	+15/+48	+12%/+37%
		wet	93.7–99.7	90–101	0.74–1.25	38	28–47	–10/+9	–26%/+24%
		slip	86	56–76	0.28–0.69	45	13–31	–32/–14	–71%/–31%
	darkness	dry	103–107.5	52–107	0.11–1.12	40	4–45	–36/+5	–90%/+12%
110 Mw	day-light	dry	107.5–114	110	0.90–1.07	58	52–62	–6/+4	–10%/+7%
		wet	101–102	90–101	0.68–1.00	18	12–18	–6/+/–0	–33%/ 0%
		slip	97	56–76	0.19–0.48	15	3–7	–12/–8	–80%/–53%
	darkness	dry	111.4–113	107	0.85–0.88	18	15–16	–3/–2	–17%/–11%
All estimable conditions						7,986	4,600–6,037	–3,386/–1,949	–42%/–24%
Conditions with missing present speed data* (wet/slippery road in darkness)						4,755	2,758–3,614	–1,997/–1,141	–42%/–24%*
Unspecified accidents						3,262	3,262	+/–0	+/–0
Total						16,003	10,620–12,913	–5,383/–3,090	–34%/–19%

* with the assumption of the same effects in these conditions (wet/slippery road in darkness) as for the estimable conditions (dry/wet/slippery road in daylight and dry road in darkness).

modified by other “safety” devices e.g., Adaptive Cruise Control, UV headlights, Driver Status Monitoring, etc. However the interactions of these devices may increase or decrease safety. Many of the “safety” devices will probably not bring about the expected safety effects on their own due possibly to negative behavioural adaptations, but combined with dynamic speed adaptation they could give synergistic effects and thus lead to real safety improvements. On the other hand, several warning and feed-back systems with their various signals may cause confusion and increase a driver’s workload.

How would the system help the individual driver? 1) Drivers systematically overestimate the effects of higher speeds on travel time, and, as a consequence, they might accept higher risks of being involved in an accident than the risk level they would accept if they had a more realistic comprehension of the real time savings. Wrong decisions based on these misjudgements can be prevented by the system. 2) The system would facilitate predicting journey time by more accurate information on road and weather conditions and due appropriate highest speeds along the route. This would help the driver in his decision on a possible earlier start and not on making up time during the journey. 3) The driver cannot read the speedometer all the time as he must concentrate on the surrounding traffic situation. When leaving a motorway or when entering streets with low speed limits after travelling at higher speeds, automatic speed adaptation should be helpful against the “speed adaptation phenomenon”.

Further research is needed in order to investigate: 1) alternative technological solutions and system safety issues; 2) the appropriate design of the human-machine interface for dynamic speed adaptation; 3) the effect on the driver’s work-load, the effects on different groups of drivers since the driver population is not homogenous and in-car systems can have different effects on different groups; 4) possible negative behaviour modifications in the form of delegation of responsibility – “the system takes care of everything”; 5) other possible adverse effects of data collection, errors or sudden changes in feedback which could surprise the driver; 6) system safety issues; 7) liability issues; 8) system financing issues (social cost, welfare benefits, etc.); 9) other applications than those discussed here (e.g., at intersections and pedestrian crossings) and implementation for other reasons than safety (i.e., improving capacity).

REFERENCES

1. Sabey, B. Accidents: their cost and relation to surface characteristics. Safety and the concrete road surface. Paper presented at the symposium: “Safety and the concrete road surface – design specification and construction”. Birmingham. (1973).
2. Schandersson, R. The relationship between traffic accidents, road conditions and winter road maintenance. A study on accident risks in different ice and snow conditions based on insurance reports. (In Swedish). VTI meddelande 496, Linköping. (1986).
3. Brüde, U., Larsson, J., Thulin, H. Traffic accidents’ relationship with road delineation – for different width, speed limit, period of the year, light conditions and region. (In Swedish). VTI Meddelande 235. Linköping. (1980).
4. Nilsson, G. The effect of speed limits on traffic accidents in Sweden. VTI Report 68, Linköping. (1982).
5. Elvik, R., Vaa, T., Östvik, E. Trafikksikkerhetshåndbok, Transportøkonomisk Institutt, Oslo. (1989).
6. Finch, D. J., Kompfner, P., Lockwood, C. R., Maycock, G. Speed, speed limits and accidents. Project Report 58. Transport Research Laboratory, Crowthorne. (1994).
7. Comte, S., Várhelyi, A., Santos, J. The Effects of ATT and Non-ATT Systems and Treatments on Driver Speed Behaviour. Working Paper R 3.1.1 in the EU-project – MASTER. (1997).
8. Várhelyi, A. Dynamic speed adaptation based on information technology – a theoretical background. PhD Thesis, Lund University. (1996).
9. SCB Traffic injuries 1993. (In Swedish). Statistiska Centralbyrån, Stockholm. (1994).
10. Nilsson, G. Speeds, accident risks and injury consequences in different road environment. (In Swedish). VTI Rapport 277. Linköping. (1984).
11. Papacostas, C. S. Fundamentals of transportation engineering. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. (1987).
12. Bontell, C. Documentation of basic journey data and road delineation. (In Swedish). TU 1983:4. Vägverket, Borlänge. (1983).
13. Janssen, W., Nilsson, L. An experimental evaluation of in-vehicle collision avoidance systems. VTI särtryck Nr 181. Reprint from DRIVE Project V1041 (GIDS). VTI, Linköping. (1992).
14. Nilsson, L., Alm, H., Janssen, W. Collision Avoidance Systems – Effects of different levels of task allocation on driver behaviour. VTI särtryck Nr 182. Reprint from DRIVE Project V1041 (GIDS). VTI, Linköping. (1992).
15. Nilsson, L. The effects of adaptive cruise controls. (in Swedish). Sektion A. In: Gustafsson, P. (ed.) ARENA, Test Site West Sweden. Learning and demonstrating new technology and design principles for road transport, Göteborg. (1996).
16. Van Winsum, W., Martens, M., Herland, L. The effects of speech versus tactile driver support messages on workload, driver behaviour and user acceptance. TNO-report. TM-99-C. (1999).
17. Webb, P. J. The effect of an advisory speed signal on motorway traffic speeds. Transport and Road Research Laboratory, Crowthorne, Berkshire. (1980).
18. Várhelyi, A. Speed management via in-car devices: effects, implications, perspectives. Transportation, Vol. 29, No. 3, pp. 237-252. (2002).
19. Gustafsson, F. Slip-based estimation of tire-road friction. Linköping University. (1993).
20. Persson, H., Towliat, M., Almqvist, S., Risser, R., Magdeburg, M. Speed Limiter in the Car. A field study on speeds, behaviour, conflicts and driver comments when driving in built-up area. (In Swedish). Lund University, Sweden. (1993).
21. Almqvist, S., Nygård, M. Dynamic speed adaptation – Demonstration trial with speed regulation in built-up area. Bulletin 154. Lund University. (1997).

ACKNOWLEDGEMENT

Financial support for this study was provided by KFB – the Swedish Transportation & Communications Research Board.