ACCIDENT REDUCTION POTENTIAL OF ADVANCED ADVERSE WEATHER WARNING SYSTEMS

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ABSTRACT

This paper presents the main results of a research project that was conducted at Madrid Polytechnic University to assess the potential of effectively reducing accident rates in adverse conditions by deploying ITS. Traffic accidents that had occurred in the Spanish National System in adverse weather conditions during a 5-year period were studied to identify road sections with an accident record that justified the implementation of specific countermeasures. American and European experience in applying RWIS and Advanced Adverse Weather Motorist Warning Systems (AAWWS) were analyzed prior to the development of three pilot tests for the deployment of AAWWS at three Spanish network sites. These tests where complemented with an in-depth study of a sample of 259 adverse conditions injury crashes. The results were used to provide an estimation of the crash reduction attainable by the deployment of these systems in Spain. The research showed that the annual savings in social costs of traffic crashes would exceed the total investment needed to deploy the systems.

1. ROAD SAFETY PROBLEMS IN ADVERSE WEATHER

The Spanish Ministry of Public Works (*Ministerio de Fomento*) sponsored a research project that was conducted at Madrid Polytechnic University to assess the potential of effectively reducing accident rates in adverse conditions by deploying ITS [1].

Spain's National Road Network includes 25,000 km of highways, 30% of which are freeways. Annual traffic exceeds 90,000 million vehicle-km, 35% of the nation's road traffic including urban traffic, and more than 54% of interurban traffic. Although the climate in Spain is moderate in the Southern, Mediterranean and Atlantic regions, the mountainous areas in central and northern Spain experiment harsh winter conditions. The risk of accident occurrence increases two to five times in adverse weather conditions.

Adverse weather conditions affect driving safety in different ways: Ice, snow or water on the roadway surface reduce pavement friction. Fog, heavy rain or snow reduce sight distances. Strong crosswinds may compromise vehicle stability.

The research started with an analysis of accident records on the Spanish national roads in the period 1997-2001 showing that 10% of the accidents occur under adverse conditions. 96,929 personal injury accidents occurred in the 5-year study period, 8,862 of which occurred under adverse weather conditions causing 955 fatalities, 9.7% of the total fatalities recorded in the National Highway System during this period. This percentage was stable during the period.

The most frequent accidents in adverse conditions were those that happened in connection with heavy rain (Fig.1). Accidents with fog or with restricted visibility due to other causes add up to 30% of the total. Strong winds account for 7% of the accidents, while the percentages of accidents that occur with snow, hail or ice on the roadway are lower than 5% in each case. Accident frequencies with ice or snow accumulation on the roadway are low. This fact indicates that preventive winter maintenance operations and snow removal tasks are carried out efficiently and effectively to prevent hazardous conditions.

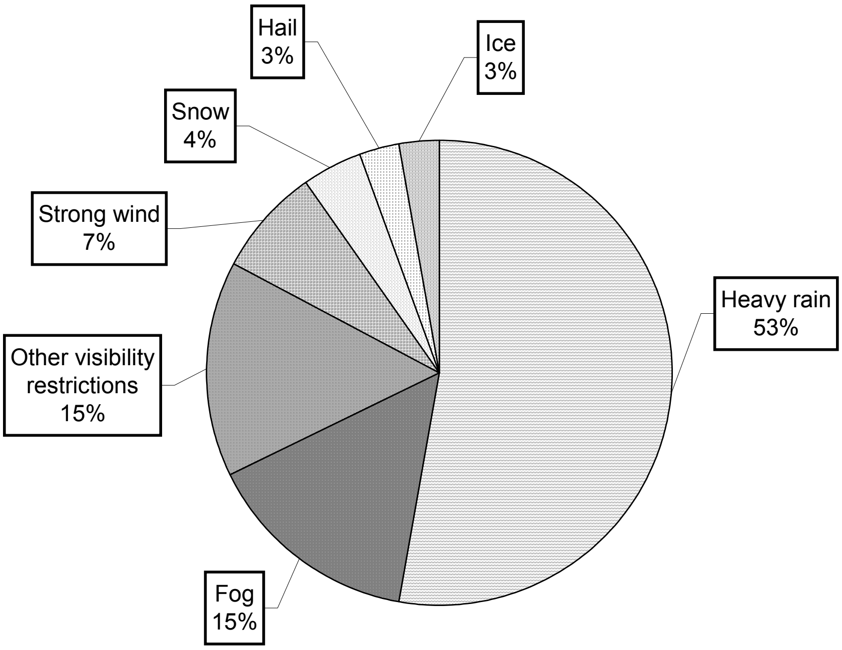

Figure 1 - Prevailing conditions in the adverse weather injury accidents recorded in the Spanish National Road System (1997-2001)

In accident reports, two thirds of the injury accidents and more than 70% of the fatalities occurring in adverse conditions are attributed to inadequate speeds of some of the vehicles involved in the accident or to driver distractions (Fig. 2). Therefore safety improvement measures should aim at achieving speed reductions, higher level of attention in drivers and increased headways when adverse conditions are present.

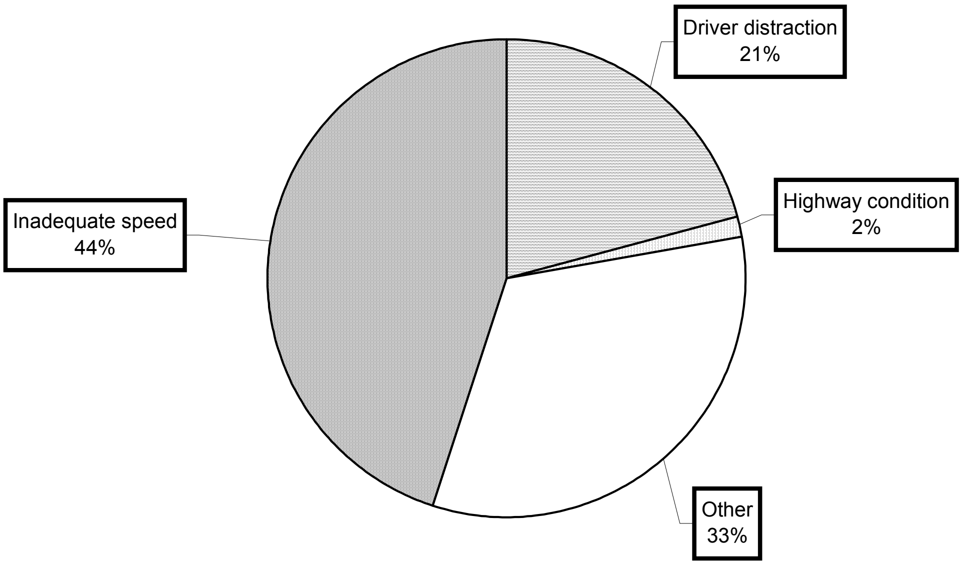

Figure 2 - Main contributing factors to adverse weather injury accidents in the Spanish National Road System (1997-2001)

Accident locations during the 5-year study period show a high degree of dispersion, and in many cases accident history does not warrant the implementation of safety countermeasures specifically designed to improve safety in adverse weather conditions.

Road sections with a length up to 10 km where at least 5 accidents had occurred in adverse weather conditions during the 5-year period, and where at least 2 accidents/km had been recorded, were selected as potential treatment sites for later analysis. Using these criteria, it was possible to identify 214 segments with a total length of 744 km, accounting for 3% of the total network. In these segments 2,395 adverse weather condition injury accidents were recorded between 1997 and 2001, corresponding to 25% of the total in the whole network.

2. APPROACHES TO ROAD SAFETY IMPROVEMENT IN ADVERSE WEATHER

Efficient management of winter maintenance operations can minimize the time during which the pavement surface friction coefficient is reduced, thus reducing the probability of accident occurrence. Road Weather Information Systems (RWIS) have been used for over 20 years to plan and manage winter maintenance operations in Northern and Central Europe, the US, Canada and Japan. Experience shows that the combination of data obtained by pavement and atmospheric sensors, thermal mapping and detailed weather forecasts for the area where winter maintenance operation is taking place results in a significant improvement in the quality of service and road safety in adverse weather situations [2].

RWIS encompass equipment and techniques that provide road agencies with real time meteorological information and enable the establishment of accurate predictions of the state of the pavement and of the evolution of weather conditions which are key to an effective management of winter maintenance resources. This information can be used to improve the response of winter maintenance crews in adverse conditions and to warn drivers thus enhancing safety levels and reducing risk of accidents. The results achieved by road agencies that apply RWIS to support winter maintenance management show that its implementation produces road safety improvements and in addition the savings derived from the higher efficiency in the operations more than compensate its costs. Data obtained in the US show that the application of RWIS can result in an average reduction of 75% on ice and snow removal. Once this has been achieved, accident rates descend 85% on two lane roads and 78% on motorways [3].

The main components of an RWIS are:

1 Environmental sensors used for collecting weather data such as air temperature, quantity and type of precipitation, visibility, dew point, relative humidity, as well as wind speed and wind direction.

2 Pavement condition sensors that collect surface data such as pavement and sub-surface temperature and surface conditions (wet, dry or freezing).

3 Thermal maps of the road network.

4 Short-term pavement temperature prediction models based on the results of general weather forecasts, information captured by road and weather sensors as well as by meteorological radars and finally statistical records of the relationship between local atmospheric variables and road conditions.

5 Communications linking sensors, the central computer, maintenance centers and maintenance crews.

Additionally, it is important that drivers reduce the speed and increase the headway when driving in adverse conditions to compensate for the lower margin of error. Data obtained in Finland show that even though drivers modify their speed when environmental conditions worsen, the speeds are still too high when friction is reduced due to the presence of snow or ice [4]. Average speeds on a slippery road surface are about 4 km/h lower than average winter operation speeds. Additionally the standard deviation of speed distribution is lower, as the reduction is more acute for the highest speeds. Nevertheless, this adaptation has been found insufficient to compensate for the increase in the braking distance, and therefore safety margins are reduced, especially in curves.

Advanced Adverse Weather Warning Systems (AAWWS) can be used to warn drivers of specific risk situations as they travel along the road network and to induce them to adapt their driving patterns accordingly.

3. ADVANCED ADVERSE WEATHER WARNING SYSTEMS

AAWWS components vary from very simple solutions constituted by a sensor that automatically actuates a warning sign when the condition reaches a pre-established threshold, to complex ones that use RWIS to estimate the conditions on a road segment, select the most adequate warning message sequence and location and to activate the corresponding VMS. In any case, the main components of an AAWWS are:

1. Adverse condition detectors
2. Variable message signs.
3. System control and operation devices.

The type of detector depends on the type of weather condition that can occur. The following types of detection devices are frequently used:

a) Visibility detectors

b) Precipitation detectors

c) Anemometers

d) Pavement condition sensors

e) Closed circuit TV cameras

f) Traffic detectors.

Providing accurate real-time warnings to motorists in extended areas is particularly challenging, as conditions frequently change. Warning messages or speed limits can be conveyed to the drivers using different types of displays:

1. Fixed signs with flashing beacons.
2. Permanent variable message signs.
3. Mobile variable message signs.

AAWWS control and operation may be run by independent controllers with a microprocessor and the corresponding operation algorithms, or remotely by the central computer of a traffic management center.

4. AAWWS OPERATION

AAWWS operation includes:

1. Transmission of the information captured by the sensors.
2. Data processing and decision making as to sign activation, message choice and message deactivation.
3. VMS operation: display, modification and removal of messages.
4. System monitoring.

The deployment of AAAWWS presents additional problems to those common to any Traveler Information System.

First, the location of the warning signs is critical for the system's effectiveness and should correspond to the sites that at a given time present critical conditions, which are not always the same. AAWWS should be deployed only at sites where a specific hazard has been identified.

Second, these systems must only be activated when the critical conditions are actually present and pose a real hazard for passing vehicles. The algorithms used to activate the warning messages must be established with the criteria of minimizing false alarms to reinforce the reliability of the system for the users.

Finally, it is vital that the warning message attracts the drivers´ attention and induces them to adapt their driving patterns. The recommendations transmitted to the drivers by the systems must be commensurate with the prevailing conditions, so that the drivers easily understand them.

In consequence, AAWWS must be designed to:

1 Select the adequate warning message at the right time.

2 Prevent transmitting inaccurate information or transmitting it too late for the drivers to react upon it.

3 Suppress the warning messages as soon as the hazardous situation disappears.

There are several possible AAWWS configurations depending on the type of operation:

a) Autonomous systems with manual operation.

b) Automated autonomous systems.

c) Systems integrated in a traffic control center with automated or assisted remote operation and monitoring.

Different procedures for optimizing the location of hazard warnings while taking into account variations in traffic flow, drivers' reactions, and randomness of weather conditions have been researched including genetic algorithms [5] and fuzzy logic [6].

5. PILOT TESTS

Three pilot tests were carried out as part of the research in order to assess the effectiveness of AAWWS in influencing driver behavior, improving safety and determining the feasibility of implementing this type of solution in the Spanish National Road Network. The trials were conducted on a two-lane road section of national road N-301 in the province of Toledo, a dual carriage road linking Madrid and Seville (N-IV), and a toll motorway in northern Spain (A-1). The three test sites experiment recurrent problems of limited visibility due to fog. For the pilot tests an autonomous system with manual operation was implemented. The warning system that was deployed included two mobile variable message signs mounted on a maintenance van and on a trolley, which were used as pre-warning and reinforcement signs respectively.

The pre-warning message warned the driver of the existence and the nature of a hazardous situation that he was going to run into at a short distance (1 to 3 km), and included a recommended speed (Fig. 3).

FIGURE 3 - Pre-warning mobile variable message sign used in AAWWS pilot tests

The second VMS was used to repeat the warning and the speed recommendation after the driver had entered the hazardous section. It was combined with a radar speed detector that automatically displayed the speed of the passing vehicles that were exceeding the recommended speed (Fig. 4).

FIGURE 4 - Reinforcement mobile variable message sign used in AAWWS pilot tests equipped with a radar speed detector

Table 1 reflects the messages that were used in the pilot studies.

Table 1 - Warning messages used in the pilot studies

Visibility (m)	Pre-warning message	Reinforcement message
>200	Not active	Not active
150-200	Lower your speed Fog 2000 m	Fog Lower your speed
100-150	Recommended speed 80 Thick fog 2000 m	Recommended speed due to fog 80 Your speed is v km/h
<100	Recommended speed 60 Very thick fog 2000 m	Recommended speed due to fog 60 Your speed is v km/h

In each pilot test, the speed distribution in the road sections where the warning messages were displayed was recorded with magnetic traffic detectors and compared with the distribution recorded with similar weather conditions when no warning signs were displayed. Average speeds when the warning signs where displayed were found to be significantly lower, as was the dispersion in the speed distribution. In some cases, the mean speed showed a reduction of over 20%, while the reduction in the standard deviation of the speed distribution reached 30%. These two effects are consistent with what has been found in other studies [7].

6. ESTIMATES OF ACCIDENT REDUCTION ATTAINABLE BY THE DEPLOYMENT OF AAWWS IN THE SPANISH SYSTEM

An in-depth study of a sample of 259 accidents was conducted at Madrid Polytechnic University to assess the reduction in accidents which could be achieved by deploying AAWWS in the Spanish National Road Network. As a result of the analysis, the accidents were classified in four categories depending on the degree on relationship found to exist between the causes that contributed to the occurrence of the accident and the factors on which the deployment of AAWWS may have a positive effect. The four categories were defined as follows:

1. Highly related: accidents attributable to the adverse conditions in conjunction with inadequate speeds and driver distractions.

2. Medium relation: accidents attributable to the adverse conditions in which inadequate speeds and driver distractions were not the only contributing factors.

3. Low relation: accidents attributable to the adverse conditions but in which inadequate speeds or driver distractions were not a contributing factor.

4. No relation: accidents not attributable to the adverse conditions.

Table 2 summarizes the results of the analysis.

Table 2 - Results of the in-depth analysis of 259 adverse weather accidents

	Potential AAWWS effect on the causes of the accidents			
	HIGH	**MEDIUM**	**LOW**	**NOT RELATED**
Heavy rain	0 %	79.4 %	5.9 %	14.7 %
Light fog	38.1 %	23.8 %	9.5 %	28.6 %
Thick fog	24.3 %	43.3 %	18.9 %	13.5 %
Other visibility restrictions	45.5 %	20 %	7.3 %	27.2 %
Strong cross winds	53.8 %	23.1 %	0 %	23.1 %
Snow	43.4 %	33.3 %	13.3 %	10 %
Ice	75 %	18.8 %	0 %	6.2 %
Hail	0 %	50 %	0 %	50 %

This study was used to estimate the potential safety improvement attainable by deploying AAWWS at the 214 segments that had been identified to present a significant concentration of adverse weather injury accidents.

To compute accident reduction factors for each of the weather situations that had been found to originate accidents in some of the 214 sections, which are suitable for the deployment of warning systems, the following formula was applied:

$$F_j = \sum_{i=1}^{4} P_i r_{i,j}$$

where

F_j : Reduction factor attainable in adverse weather accidents by the implementation of an AAWWS in highway sections where the predominant adverse weather condition was j

P_i : Probability to avoid an adverse weather accident in which the degree of relationship with the factors that are influenced by the existence of an

AAWWS is i (i takes the following values: i=1 →Highly related; i=2 →Medium relation; i=3 →Low relation; i=4 →No relation)

$r_{i,j}$: Relative frequency of accidents in which the predominant adverse weather condition is j where the degree of relationship with the factors influenced by the existence of an AAWWS is i

Table 3 reflects the resulting accident reduction factors.

Table 3 - Crash reduction factor estimates for the deployment of advanced adverse weather hazard warning systems

PREVAILING CONDITION	REDUCTION FACTOR
Heavy rain	0.~~,~~4088
Light fog	0.~~,~~4428
Thick fog	0.~~,~~4487
Other visibility restrictions	0.~~,~~4786
Strong cross winds	0.~~,~~5459
Snow	0.~~,~~5403
Ice	0.~~,~~6940
Hail	0.~~,~~4000
Dust or smoke	0.~~,~~2500
Miscellaneous	0.4761

Based on these reduction factors, the potential accident reduction in the 214 treatable sections was obtained. The resulting overall estimate showed that a reduction of 43.8% of the 480 annual injury accidents occurring in these sections could be prevented if advanced warning systems were implemented. The annual injury accident reduction would exceed 200 with 22 fatalities prevented every year. The estimated cost of the implementation of the systems needed to reach this reduction was 19,718,900 €. The annual savings in the social costs of traffic accidents would exceed the total investment needed to deploy the systems.

7. CONCLUSIONS

The following conclusions can be drawn from the results presented in this paper:

1 Adverse weather poses significant road safety problems. In particular, in Spain adverse weather accidents account for 10% of the total injury accidents and traffic fatalities. This percentage has been found to be stable and warrants considering measures specifically devised to improve safety in adverse weather conditions.

2 In Spain, two thirds of the injury accidents and more than 70% of the fatalities that occur in adverse conditions are in accident reports attributed to inadequate speeds of some of the vehicles involved in the accident or to driver distractions. Therefore safety improvement measures should aim at achieving speed reductions, higher level of attention in drivers and increased headways when adverse conditions are present.

3 To implement specific accident reduction countermeasures, it is necessary to identify the highway sections where a significant concentration of adverse conditions had occurred and where specific countermeasures could be justified.

4 Properly designed and operated advanced warning systems can provide reductions of up to 40% in personal injury accidents in adverse weather conditions. This reduction can reach 85% when the hazardous conditions are due to the existence of fog.

5 The social savings derived from the accident reductions that can be obtained by the deployment of AAWWS in the Spanish system would completely cover the required investment in one year.

REFERENCES

1. Pardillo Mayora, J. (2004): ·Aplicaciones ITS para aumentar la seguridad vial con meteorología adversa”. Estudios de Construcción y Transportes nº 100, enero a junio 2004, pags. 29 a 50. Ministerio de Fomento, Madrid, Spain.
2. Pardillo Mayora, J (1998): “Sistemas de información meteorológica para la gestión de operaciones preventivas de vialidad invernal”. Rutas nº 65. Asociación Técnica de Carreteras. Madrid, Spain
3. Federal Highway Administration (1997): Snow and Ice Control. Road Savers, FHWA-SA-97-035. Washington DC, USA
4. Kulmala, R and Rama, P. The Effects Of Weather and Road Condition Warnings on Driver Behavior. Road Safety in Europe and Strategic Highway Research Program ,SHRP. Swedish National Road and Transport Research Institute, Linkoping, Sweden
5. Abbas, M and McCoy, P. (1999):Optimizing Variable Message Sign Locations on Freeways Using Genetic Algorithms. 78th Annual Meeting Proceedings, Transportation Research Board, Washington DC, USA.

6. Placer, J. and Sagahandroon, A. (1998): Fuzzy Variable Speed Limit Device Project. Department of Computer and Electrical Engineering. Northern Arizona University, Flagstaff, AZ, USA.
7. Robinson, M. (1997):. Examples of Variable Speed Limit Applications. Speed Management Issues Workshop, 79th TRB Annual Meeting. Transportation Research Board, Washington DC, USA