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Model for the Safety Impacts of Road Weather Information Services Available to Road Users and Related Socio-Economic Benefits

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Abstract

Weather-related information and warnings are typically distributed to road users via mass media such as television, radio and Internet. The socio-economic benefits of these services should be known at least approximately before major decisions are made on service provision and related investments. This paper presents a method for estimating a likely range of safety impacts obtained with weather-related information and warning services available to road users and the related socio-economic benefits. The theoretical framework behind the model is the principle that the number of accidents is dependent on the exposure to risk and the probability of accident occurrence. Information on the effects of road weather information and warning services on the safety of road users was collected by means of a literature study and expert interviews. The strength of the model lies in its ability to produce meaningful quantitative results with minimal amounts of collected information and the ease with which the model can be applied and adapted in various types of evaluation studies. The results obtained with the model will be most reliable in countries in which the factors contributing to weather-related accidents are similar to those in the Nordic countries.

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1. Introduction

Weather and road surface conditions are widely known to affect the safety of road users. For example, in the USA accident statistics based on weather and road surface status are available from the National Highway Traffic Safety Administration (NHTSA) [1]. According to a European review, the accident risk can be about six times higher on roads with ice or snow than on "black roads". On steep gradients, the risk can be 10 times higher. The risk depends on how common the ice and snow conditions are. If such conditions are commonplace for the drivers, the accident risk is roughly double that on black roads, but if they are uncommon the risks can be 30-40 times higher [2]. An overview of the impacts of winter weather on the safety of road users is found in a literature review by Strong, Ye and Shi [3].

The last 10 years have seen significant progress in meteorology, data processing, data communications and information technology. At the same time, meteorological information and warning services tailored to road users have been developed further in terms of information content, availability and accuracy. With current technology road users can be warned in real time when road conditions turn hazardous because of ice on the road surface, snow, heavy rain, fog or other weather-related phenomena or conditions. At present, warnings and information on weather and road conditions are distributed via mass media such as TV and radio and the web sites of broadcasting stations, road authorities, meteorological institutes and service providers and other organisations (for Finnish examples, see [4-7]).

Considerable investment is needed in data collection, data processing, operation of services, and delivery of information from service provider to end-user. This means that the benefits of these services should be known at least approximately before major decisions are made regarding service provision and investments. To date there has been no widely applicable methodology for estimating the most likely impact of weather-related information and warning

services on the safety of road users and the corresponding socio-economic benefits. Typically, a rough estimation of the most probable range of likely socio-economic benefits is enough to support decision making related to investments and service provision. This can be achieved by developing a simplistic model for the safety impacts and related socio-economic benefits of road weather information services available to road users. The model is a compromise between the need for accuracy and the limited availability of information to be used as source data and resources needed for analysis. However, it is assumed to produce the correct range for the socio-economic benefits of weather-related information and warning services offered to road users. Only the effects on the safety of road users were included in the model.

2. Development of the model

A mathematical model for accident reduction related to information and warning services was built on the basis of estimates made by the authors and available statistics on traffic safety and weather. The model was built with estimates and data related to conditions in Finland, then generalised to other countries. The theoretical framework behind the model is the principle that the number of accidents is dependent on the exposure to risk and probability of accident [8]. Costs incurred by accidents are dependent on the numbers of different types of accidents during the period under study and the unit cost values of different types of accidents [9]. Information on the effects of road weather information and warning services on the safety of road users was collected by means of a literature review and expert interviews. Monetary valuation of safety benefits is based on unit values published by the Finnish Road Administration [10]; the Finnish unit values were scaled with gross domestic product (GDP) per capita adjusted with relative purchasing power when applied to countries other than Finland.

The literature study yielded no models that could be readily applied, and only a limited number of studies on the impacts of road weather information services on road safety. The most relevant of these studies are referred to below.

In many countries, weather poses a significant challenge to road traffic and road maintenance. Snow and icy road surfaces reduce the friction of vehicle tyres. Snow, heavy rain or fog affects visibility. Weather and road conditions are highly time-variant phenomena: temperature, rainfall, and the state of the road surface may change from one hour to the next. For example, changes in temperature can make roads suddenly very slippery in winter. Unfortunately, drivers do not always adapt their driving behaviour to the changing weather and road conditions [11-12].

When drivers are informed of weather and road conditions, they can adapt their behaviour accordingly by reducing their speed and increasing their alertness. The high accident risks caused by adverse weather conditions can thereby be decreased by providing information, warnings and support to road users.

Peirce and Lappin [13] studied drivers' readiness to utilise different traffic-related information via radio, TV, Internet and changeable/variable message signs. Drivers reported using some traffic-related information during only 10% of journeys, and changing their behaviour due to the information during only 9% of these journeys. According to Peirce and Lappin, the small utilisation may be due to several factors such as lack of knowledge about the information services, a high proportion of journeys requiring no special information, lack of information for the route used, or poor quality of information. The results indicated that drivers were considerably more apt to acquire information when it was regarded as useful — information was

sought for journeys during morning peak hours five times more frequently than on average [13].

In countries with frequent occurrence of adverse weather problems, it is likely that drivers are interested in acquiring road weather-related information before and during their journeys. In 1997–2007, poor road weather conditions were predicted about 27–35% and hazardous conditions 2–5% of the time during the winter season, at least in some parts of Finland [14].

Rämä and Kulmala [15] showed that slippery road warning VMS (Variable Message Signs) decreased mean speeds by around 1-2 km/h when the signs were lit. The system was also shown to affect the direction of attention to find cues showing potential hazards, and to make passing behaviour more careful, indicating an even larger positive impact on safety than that due to lower speeds [16]. Kilpeläinen and Summala [17] studied the effects of weather and weather forecasts on self-reported driver behaviour in Finland. They found the Finnish Road Weather Information Service to have no impact on the self-reported on-road driving behaviour but 5.8% of interviewed drivers reported changes in travel plans before or during the trip. The most frequently reported changes were allowing more time for the trip, altering the time of departure and changing route.

An automatic fog-warning system on the M25 motorway in England displayed the "Fog" legend on roadside matrix signals. Assessment of this system showed that the net mean vehicle speed reduction was around 3 km/h when the signals were switched on as a result of the formation of fog [18].

Real-time information on slipperiness and other road weather-related problems via collective media such as radio has been estimated to reduce the risk of injury accidents in adverse conditions by 8% on main roads and 5% on minor roads in Nordic conditions [19].

Road weather information and warnings are usually provided to the users only in cases where the road weather conditions are currently or soon expected to be adverse. Hence, road weather information is not assumed to have major impacts on good road weather conditions. The effects of road weather information and warnings likely also vary according to the type of road weather conditions. This was indicated by Rämä [20], who showed that the effects of road weather information and warnings had stronger impacts in conditions where the drivers had difficulty detecting the conditions by themselves, such as black ice, than when the adverse situations were easy to detect, such as snow on the road. Even in the latter, information and warnings at the roadside were found to decrease driver speeds. As no universal categorisation of road weather conditions is available, we decided to look at adverse road weather conditions generally, assuming a similar distribution based on the degree of ease in detecting them.

The effect model should also consider effects related to the amount or pattern of travel, i.e. exposure to different conditions. The traffic exposure in various road weather conditions was assumed to stay constant at least in the first model version. In other words, the safety impacts related to major changes in departure times, change of the mode of transport or cancelling journeys were assumed to be considerably smaller than impacts related to the changes in driver alertness and driving speed.

Weather-related information and warning services distributed via mass media to road users were assumed to reduce by 1-2% the number of all accidents involving personal injury or death on public roads in Finland. This estimate was based on the results of evaluations on

Finnish VMS-based road weather warnings and speed control and the relationship between speed and the number of accidents involving personal injury or death documented by Nilsson [21]. Similar results have been obtained with a Delphi study conducted in 2007, which was answered by 135 Finnish and international experts [22]. When the accident reduction in percent, the number of accidents on public roads and the monetary unit values for different types of accidents are known, it is quite simple to calculate the socio-economic benefit.

In the case of Finland, the reduction in the number of accidents involving personal injury or death on public roads can be calculated with the formula

$$a = |x_{after} - x_{before}| = |x_1 - x_0| = \left| x_1 - \frac{1}{1-p} * x_1 \right| = \frac{1}{1-p} * x_1 - x_1 \quad (1),$$

where p is the relative accident reduction achieved with weather-related information and warning services and x_1 is the number of accidents involving personal injury or death on public roads in Finland during 1 year at present. Variable x_0 represents the number of accidents involving personal injury or death in a situation where no weather-related information or warning services were available to road users. Variable x_0 can be calculated by assuming that present information and warning services reduce the number of accidents by p percent:

$$x_0 = \frac{x_1}{(1-p)} \quad (2).$$

The socio-economic benefit from the reduction in the number of accidents involving personal injury or death can be obtained by multiplying the reduction in the number of accidents by the corresponding unit cost value u_{id}

$$M = a * u_{id} = (x_0 - x_1) * u_{id} \quad (3)$$

In Finland, commonly agreed unit cost values for different types of road accidents have been published by the Finnish Road Administration [10]. The unit cost for an accident involving personal injury or death in Finland has been estimated at 471 000 euros.

In addition to injury accidents and fatal accidents, there is an effect on the number of accidents involving only property damage. Weather-related information and warning services affect the number of accidents, including those resulting in property damage only, mainly in two ways. After receiving information or a warning, a driver may lower his or her speed or increase his or her alertness [16, 22] to road weather problems ahead.

Let us first study the effect due to speed reduction. According to Nilsson [21], the number of accidents involving personal injury or death increases with the average speed of traffic in relation to the second power of the ratio of average speeds before and after the increase in average speed:

$$\frac{x_1}{x_0} = \left(\frac{V_1}{V_0} \right)^2 \quad (4).$$

Nilsson's study presents no similar relationship for average speed and accidents involving only property damage. However, with the two previous formulae and some assumptions, one can establish a link between the reduction in number of accidents involving death or personal injury and the reduction in number of accidents involving only property damage.

It is reasonable to assume that the effect of weather-related information and warning services on the number of accidents involving only property damage is related partly to speed and partly to the increased alertness of road users. Both these factors can be assumed to have

equal weight. The effect of speed on the number of accidents involving only property damage can be assumed to be

$$\frac{x_{1(property)}}{x_{0(property)}} = \left(\frac{V_1}{V_0} \right) \quad (5).$$

This assumption is based on results of speed limit experiments carried out in Finland [23] and a meta-analysis combined with a literature study [24].

The second part of the effect arises from the increased alertness of road users. The larger the reduction in speed, the greater the effect of alertness on the number of accidents can be assumed. The effect of increased alertness of road users on the number of accidents involving only property damage can be assumed to be

$$\frac{x_{1(property)}}{x_{0(property)}} = \left(\frac{V_1}{V_0} \right)^2 \quad (6).$$

If both the effects (speed and alertness) are considered important, one can calculate the change in the number of accidents involving only property damage as a function of the ratios of average speeds:

$$\frac{x_{1(property)}}{x_{0(property)}} = \frac{1}{2} \left(\frac{V_1}{V_0} \right) + \frac{1}{2} \left(\frac{V_1}{V_0} \right)^2 \quad (7).$$

Based on (4) one can calculate “backwards” the ratio of average speed derived from the numbers of accidents involving injury or death:

$$\frac{x_1}{x_0} = \left(\frac{V_1}{V_0} \right)^2 \quad (8)$$

$$\left(\frac{V_1}{V_0}\right) = \sqrt{\frac{x_1}{x_0}} \quad (9).$$

By substituting V_1/V_0 in (7) with the right side of (9), one can describe the relationship between the number of accidents involving only property damage and accidents involving personal injury or death as follows:

$$\frac{x_{1(property)}}{x_{0(property)}} = \frac{1}{2}\left(\frac{V_1}{V_0}\right) + \frac{1}{2}\left(\frac{V_1}{V_0}\right)^2 = \frac{1}{2}\sqrt{\frac{x_1}{x_0}} + \frac{1}{2}\left(\frac{x_1}{x_0}\right) \quad (10).$$

The reduction in accidents involving only property damage can be described with the following equation:

$$\frac{x_{1(property)}}{x_{0(property)}} = 1 - p_{property} \quad (11),$$

in which $p_{property}$ is the reduction in accidents involving only property damage in percent.

By substituting the left side of (11) with the right side of (10), one can write

$$\frac{1}{2}\sqrt{\frac{x_1}{x_0}} + \frac{1}{2}\left(\frac{x_1}{x_0}\right) = 1 - p_{property} \quad (12),$$

in which

$\left(\frac{x_1}{x_0}\right)$ can be replaced with $(1 - p)$,

because

$$x_0 = \frac{x_1}{(1 - p)} \quad (13)$$

The result is the equation

$$\frac{1}{2}\sqrt{(1 - p)} + \frac{1}{2}(1 - p) = 1 - p_{property} \quad (14),$$

which can be rearranged to form

$$p_{property} = 1 - \frac{1}{2}\sqrt{(1-p)} - \frac{1}{2}(1-p) \quad (15).$$

The reduction in the number of accidents involving only property damage (in percent) is expressed in (15) as a function of reduction in accidents involving personal injury or death (in percent).

The number of accidents involving property damage that were avoided only because of weather-related information and warning services can now be calculated on the basis of $x_{1(property)}$ (number of accidents involving property damage only in one year) and $p_{property}$:

$$b = |x_{(property)after} - x_{(property)before}| = |x_{1(property)} - x_{0(property)}| \quad (16)$$

$$b = \left| x_{1(property)} - \frac{1}{1-p_{property}} * x_{1(property)} \right| = \frac{1}{1-p_{property}} * x_{1(property)} - x_{1(property)} \quad (17)$$

$$b = \frac{1}{1 - \left(1 - \frac{1}{2}\sqrt{(1-p)} - \frac{1}{2}(1-p) \right)} * x_{1(property)} - x_{1(property)} \quad (18)$$

$$b = \frac{1}{\frac{1}{2}\sqrt{(1-p)} + \frac{1}{2}(1-p)} * x_{1(property)} - x_{1(property)} \quad (19)$$

By extending (3) to include both accidents involving personal injury or death and accidents involving only property damage, a monetary value for the socio-economic benefit can be calculated as follows:

$$M = a * u_{id} + b * u_p = (x_0 - x_1) * u_{id} + \left(\frac{1}{1-p_{property}} * x_{1(property)} - x_{1(property)} \right) * u_p \quad (20).$$

$$M = a * u_{id} + b * u_p = (x_0 - x_1) * u_{id} + \left(\frac{1}{\left(\frac{1}{2} \sqrt{1-p} \right) \frac{1}{2} (1-p)} \right) * x_{1(property)} - x_{1(property)} * u_p$$

(21).

3. Generalisation of results to other countries

If one aims to generalise this approach to other countries, the analysis becomes more complex. First, the share of road accidents occurring in adverse weather or road conditions is obviously different in countries with a different climate, transport system and road user behaviour. Secondly, there are differences in the overall level of traffic safety between countries, and finally, commonly agreed unit cost values for different types of road accidents are not available for all countries. These differences must be considered when the model is generalised for use in other countries than Finland.

To take into account the differences in sensitivity to weather, the Finnish 1-2% effect on the number of accidents involving personal injury or death should be scaled appropriately. One way of doing this is to look at the relative share of accidents occurring in adverse weather or road conditions. In Finland, 21.4% of deaths and 22.3% of injuries in road accidents occur when the road surface is snowy, slushy or icy [25]. The number of accidents involving property damage only during 1 year on public roads (9 951 accidents) is available in the statistics maintained by the Finnish Motor Insurers' Centre [26].

For a given country, finding the corresponding percentages for the share of accidents in adverse weather conditions (q_d for fatal accidents and q_i for injury accidents) allows the scaled values of p for that country to be calculated as follows:

$$p_d = \frac{q_d}{q_d(finland)} * p \quad (22)$$

$$p_i = \frac{q_i}{q_{i(\text{finland})}} * p \quad (23).$$

As we have shown, the recent values for Finland were: q_d (Finland) = 0.214 and q_i (Finland) = 0.223. In some cases, the values of q_d and q_i cannot be obtained from the traffic safety statistics of the country in question. In these cases one can use values obtained from expert interviews or from other countries with a similar transport system, climate and road user behaviour.

Note that this assumes that the reduction of injury accidents in adverse conditions due to weather information is constant everywhere. We know that p is affected by the quality of weather information services as well as the frequency of adverse conditions. We can expect p to increase with increasing quality of service. We expect p to decrease with an increasing frequency of adverse conditions, as the more commonplace warnings become the less attention they will attract. As service levels probably decrease in line with the frequency of adverse conditions, these effects will mostly compensate for each other. Hence, we can probably assume that the reduction of injury accidents in adverse conditions will be of the same general magnitude.

When the effects on the number of fatal accidents p_d and on the number of injury accidents p_i are known, the reduction in number of fatal and injury accidents can be calculated in the same way as in the Finnish case:

$$a_{c(\text{injury})} = a_{c(i)} = |x_{c(\text{after})} - x_{c(\text{before})}| = |x_{c1} - x_{c0}| = \left| x_{c1} - \frac{1}{1-p_i} * x_{c1} \right| = \frac{1}{1-p_i} * x_{c1} - x_{c1} \quad (24)$$

$$a_{c(\text{death})} = a_{c(d)} = |y_{c(\text{after})} - y_{c(\text{before})}| = |y_{c1} - y_{c0}| = \left| y_{c1} - \frac{1}{1-p_d} * y_{c1} \right| = \frac{1}{1-p_d} * y_{c1} - y_{c1}$$

(25).

Variable y_{c1} in (25) represents the number of fatal road accidents during 1 year on public roads in the country to be analysed, while variable y_{c0} refers to the number of fatal accidents during 1 year in a situation where no weather-related information or warning services are available to road users.

Reduction in accidents involving only property damage can be calculated similarly to the Finnish case by using (19):

$$b_c = \frac{1}{\frac{1}{2}\sqrt{(1-p_c)} + \frac{1}{2}(1-p_c)} * x_{c1(property)} - x_{c1(property)} \quad (26),$$

where $x_{c1(property)}$ is the number of accidents involving only property damage during 1 year on public roads in the country under analysis. Variable p_c in the equation is the reduction in accidents involving personal injury or death, which can be calculated, when $x_{c1(i)}$, $x_{c1(d)}$,

$a_{c(injury)}$ and $a_{c(death)}$ are known, as follows:

$$p_c = 1 - \frac{x_{c1} + y_{c1}}{x_{c1} + a_{c(injury)} + y_{c1} + a_{c(death)}} \quad (27).$$

The socio-economic benefit during 1 year can then be calculated with equation

$$M_c = a_{c(death)} * k_c * u_{(d)} + a_{c(injury)} * k_c * u_{(i)} + b_c * k_c * u_{(p)} \quad (28),$$

where $a_{c(death)}$ is the reduction in the number of accidents involving death during 1 year on public roads in the country under analysis, $a_{c(injury)}$ is the corresponding figure for accidents involving human injury but not death, b_c is the reduction in accidents involving only material

damage, and multiplier k_c is used to scale the Finnish unit cost values for different types of accidents. Multiplier k_c is calculated with the equation

$$k_c = \frac{\frac{GDP_{c(ppp)}}{population_c}}{\frac{GDP_{fi(ppp)}}{population_{fi}}} \quad (29),$$

where the gross domestic product per capita of the country under analysis is divided by the gross domestic product (GDP) per capita of Finland. The GDP values used in the equation are values adjusted with purchasing power parity to take into account the differences in the purchasing power of the same amount of money in different countries.

Note that (29) assumes that the unit accident costs are proportional to GDP per capita. A large part of the costs associated with the accidents and their consequences are related to GDP as shown in the COST313 Final Report [27]. A large amount of costs is also attributed to so-called "human costs" reflecting the amount of pain and suffering in addition to the economic value of lost labour. As the aim is to estimate the costs approximately rather than strictly accurately, the generalisation of (28) is probably acceptable. Naturally, researchers should use the unit accident costs of the country when available.

4. Application of the model in Finland and Croatia

The model described above has been applied to Finnish and Croatian data to estimate the most likely impacts of weather-related information and warning services on the safety of road users and corresponding socio-economic benefits [28-29]. The values of inputs and outputs of the model are taken from Leviäkangas et al. [28] and Öörni [29].

The values used as inputs for the model are listed in Table 1.

Table 1. Input values for the model in the Finnish evaluation case.

Variable	Value	Low	High	Symbol
Relative accident reduction achieved with weather-related information and warning services		1%	2%	p
Number of accidents involving personal injury or death on public roads in Finland during 1 year, present	3 291			x_1
Number of accidents involving property damage only during 1 year, present	12 755			$x_{1(property)}$
Unit cost of accident involving personal injury or death	471 000 euro			u_{id}
Unit cost of accident involving property damage only	2 700 euro			u_p

The intermediate and final results provided by the model for Finland are listed in Table 2.

Table 2. Intermediate and final results provided by the model for Finland [29].

Variable	Low	High	Symbol
Estimated number of accidents involving personal injury or death when no weather-related information or warning services are available to road users	3 324	3 358	x_0
Reduction in the number of accidents involving personal injury or death on public roads	33	67	a
Number of property-damage-only accidents, avoided only because of weather-related information and warning services	96	195	b
Socio-economic benefit related to reduction in the number of accidents involving personal injury or death	15.7 M€	31.6 M€	
Reduction in accidents involving only property damage in percent	0.75%	1.50%	$P_{property}$
Estimated number of accidents involving property damage only, when no weather-related information or warning services are available to road users	12 852	12 950	$x_{0(property)}$
Socio-economic benefit related to reduction in the number of accidents involving only property damage	0.36 M€	0.72 M€	

After building the model from data available in Finland, the impacts and socio-economic benefits were estimated for Croatia. The input values for the model in the Croatian case are listed in Table 3.

In the case of Croatia, accidents during snowfall or fog were considered to have occurred in adverse weather conditions.

Table 3. Input values for the model in the Croatian evaluation case.

Variable	Value	Symbol
Number of fatal accidents on public roads in Croatia during 1 year (2005)	530	y_{c1}
Number of injury accidents on public roads in Croatia during 1 year (2005)	15 149	x_{c1}
Number of accidents involving property damage only in Croatia during 1 year	42 453	$x_{c1(property)}$
Share of fatal accidents in adverse weather conditions, Croatia	2.54%	q_d
Share of fatalities in adverse weather conditions, Finland	21.4%	$q_{d(finland)}$
Share of injury accidents in adverse weather conditions, Croatia	3.63%	q_i
Share of injuries in road accidents in adverse weather conditions, Finland	22.3%	$q_{i(finland)}$
Number of inhabitants, Finland	5.255 million	
GDP (Finland, adjusted with purchasing power parity)	139 332 million €	
Number of inhabitants, Croatia	4.439 million	
GDP (Croatia, adjusted with purchasing power parity)	50 831 million €	

The final and most relevant intermediate results obtained for Croatia are summarised in Table 4.

Table 4. Intermediate and final results provided by the model for Croatia.

Variable			Symbol
	Low	High	
Reduction of the number of fatal accidents in percent, Croatia	0.11%	0.23%	p_d
Reduction of the number of injury accidents in percent, Croatia	0.17%	0.34%	p_i
Reduction in accidents involving only property damage in percent	0.13%	0.25%	$p_{property}$ (Croatia)
Estimated number of injury accidents when no weather-related information or warning services are available to road users	15 148	15 201	x_{c0}
Estimated number of fatal accidents when no weather-related information or warning services are available to road users	531	531	y_{c0}
Estimated number of property-damage-only accidents when no weather-related information or warning services are available to road users	42507	42560	$x_{c0(property)}$
Reduction in the number of accidents involving personal injury on public roads	25.81	51.71	
Reduction in the number of fatal accidents on public roads	0.6	1.21	
Reduction in the number of accidents involving property damage only	53.63	107.41	
Socio-economic benefits related to improved safety during 1 year	4.32 M€	8.65 M€	M_c

5. Discussion

The model presented is easily used when the following statistics are available for the country to be analysed: the number of different types of accidents during 1 year on public roads, road accidents in adverse weather and road conditions, and GDP and purchasing power parity per capita. Use of the model becomes more complicated and the results less reliable when some of these initial values are not available as statistics. There are also differences in the reliability, availability and content of road accident statistics between countries. In general, accidents involving human injury or death are better documented and reflected in statistics than accidents involving only material damage.

In Croatia, the annual numbers of fatal and injury accidents are somewhat larger than in Finland, but smaller shares of fatal or injury accidents occur in adverse road weather conditions. The GDP per capita of Croatia is also less than in Finland. The estimates obtained for annual socio-economical benefits in Croatia can be said to be in line with these basic facts.

When the model was developed, one of the assumptions was that the existing information and warning services available to road users have an effect on the numbers of different types of accidents. This assumption was considered reasonable, because most countries already have at least a basic level of these services. The assumption on the magnitude of the effect in Finnish conditions was based on a literature review as well as empirical results concerning the effects on driver behaviour. This estimate is likely to be sufficiently reliable, as results obtained with a Delphi study point in the same direction. Further study on the magnitude of the effect on the number of accidents was considered to be outside the scope of this paper. Due to the nature of evidence available about the impacts of weather information on the safety of road users, we are unable to assign confidence intervals to the model estimates.

However, the model allows the calculation of upper and lower boundary values for the benefits most probably obtained in the country to be analysed. Among other things, the effect on the behaviour of road users and also the benefits obtained depends on geographical coverage of the services, information quality, information content, service availability and user perception of the services. The more localised, accurate and timely information and warnings are provided and the better they are targeted to the right audience, the larger will be the effects on the behaviour of road users and also the benefits obtained. It is also obvious that the results to be obtained with the model described in the paper will not replace a complete and detailed impact assessment carried out for an existing service whose content, implementation and user base are known.

The effect on the number of accidents in percent in the country to be analysed is obtained by scaling the effect most probably existing in Finnish conditions. The objective is to scale the exposure to the risks related to driving in adverse weather or road conditions. This calculation produces meaningful results if the factors contributing to accidents that occur in adverse weather or road conditions are mostly similar in Finland and in the country under analysis. Naturally, many factors contributing to weather-related accidents are common to several countries, but there are also some differences. For example, in some countries weather-related accidents are more commonly associated with lack of visibility than reduced friction. However, the fact that road users do not adequately adapt their behaviour to the changing weather and road conditions to compensate for the increased risk of accident is not a phenomenon specific to the Nordic countries [30]. In any case, one should consider whether the assumptions related to the model documented in this paper are appropriate for the country under analysis.

The estimated safety effects of road weather information and warnings are quite small. It should be noted that the effects are substantial in adverse road conditions, and only the infrequent occurrence of such conditions make the overall impact on the total number of road accidents and their victims much smaller. On the other hand, the costs of road weather information and warnings are also reasonably small.

The question also arises whether such a simple model is able to provide correct and meaningful results. Based on experience with predictive road accident modelling, it has been shown that simple models often perform almost just as well as very complicated ones (e.g. [31]).

It could also be asked whether the values of parameters included in the model – especially the reduction in injury accidents assumed for Finland – have been determined in an acceptable way. Even though the parameters are not directly based on controlled before-and-after studies related to weather or traffic information disseminated via mass media, they have been determined in a transparent way on the basis of systematic collection of information and they can be assumed to reflect the best available knowledge about the subject. The values of different parameters can also be changed as new and more accurate data and information become available.

6. Conclusions

The model can reasonably be assumed to provide an approximately correct range for the socio-economic benefits of weather-related information and warning services in the context of road traffic. However, it should be remembered that outputs generated by the model are only as reliable and accurate as the values fed into it. The strength of the model lies in its ability to produce meaningful quantitative results with minimal amounts of collected information and the ease with which it can be applied and adapted in different evaluation studies. The results obtained with the model will be most reliable in countries in which contributory factors behind weather-related accidents are similar to those in the Nordic countries.

It can be argued that the model is too simplistic, even naïve, in focusing only on the speed and alertness impacts of road weather information and warnings, and in assuming that the effects do not vary according to the type of adverse road condition or the dissemination media used for the information and warnings. First, our sole purpose was to develop a simple model. Second, as shown by Peltola, Kulmala and Kallberg [31], the predicting power of models is likely not considerably increased by making them more complicated through the addition of new independent or explanatory variables once the few most crucial ones have been included. According to the current empirical evidence, the impacts are mostly due to changes in driving

speed and alertness, and do not greatly differ according to the media used. The type of road condition influences the magnitude of the impact, however, and should be included in the model in the future as we accumulate more knowledge of the impacts of road weather information and warnings in different road weather conditions.

7. References

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