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Effects of weather and weather forecasts on driver behaviour

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Abstract

Winter-time slipperiness is a considerable source of elevated road accident risk, especially in northern countries such as Canada, Finland and Sweden. The national road administrations often offer a service to inform drivers of forthcoming weather and driving conditions in different regions. This study addressed the effects of adverse weather and traffic weather forecasts on driver behaviour in Finland. Drivers ($n = 1437$) answered a questionnaire on perceptions of weather, self-reported driving behaviour, pre-trip acquisition of weather information, and possible travel plan changes. The questionnaires were distributed and instantaneously collected in rural service stations in different weather and driving conditions. Data from traffic weather forecasts, automatic traffic counters and weather measurement stations concerning the same area (and road) were also collected. Acquisition of weather information for the trip was associated with low recent driving experience, increasing age, female gender, long trip in question and very poor (local) conditions perceived by the driver. Drivers who had acquired information had also made more changes to travel plans, but information acquisition did not have an effect on their on-road driving behaviour. However, they estimated prevailing risks higher than those who did not acquire weather information. Drivers generally considered the driving conditions better than the forecast, but significantly less so in darkness than in daylight or civil twilight. Leisure trips were clearly underrepresented during very poor driving conditions forecasts, suggesting that some trips are postponed as a result of adverse weather conditions or forecasts thereof. Drivers reported various kinds of compensatory behaviour during adverse conditions, including a 6–7 km/h target speed decrement. This corresponded to traffic flow speed measurements. The results suggest that the on-road driving behaviour is predominantly affected by the prevailing observable conditions, rather than traffic weather forecasts. It is suggested that if administrators wish to help drivers in adjusting their on-road behaviour in adverse weather conditions, the methods should be more local and technical by nature.

Keywords: Weather; Weather forecasts; Driver behaviour; Darkness; Risk perception; Road conditions; Expert system; Driving speed

1. Introduction

Adverse weather and road conditions, following e.g. rain, snowfall and temperature fluctuations, are a considerable cause of an elevated risk of traffic accidents and compromised traffic flow in northern Europe and

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northern America. In Finland, Malmivuo and Peltola (1997) estimated that during winter the risk factor of accidents leading to injuries or fatalities is 9 on snowy roads and 24 on icy roads, as compared to bare roads. Shankar, Mannering, and Barfield (1995) reported that maximum rainfall, rain days per month, and maximum snowfall contribute to higher accident rates in north-western USA. In the same area, Khattak and Knapp (2001) concluded that crash rates significantly increase during snow events and that snowstorm duration, snowfall intensity, higher wind speeds and greater traffic intensity further increase the risk. Andrey, Mills, Leahy, and Suggett (2003) have presented a thorough review on weather and accident risk. They draw four main conclusions that are very relevant to this study: (1) Collision risk usually increases during precipitation, the typical estimate in more rigorous studies being a 50–100% increment. (2) Considerable amount of evidence suggests that snowfall has a greater effect than rainfall, albeit fewer fatalities per collision. (3) Risk is highest for freezing rain/sleet and the first snowfalls of the season. (4) There may be differences in crash types between times of precipitation and other times. Eisenberg and Warner (2005) recently analysed over 30 million crashes in the US and reported less fatalities but more injuries and vehicular damages on snow fall days in comparison to dry days. First snow fall days of a year were especially prone to increase accidents, including fatal ones.

Although the risk estimates vary, the general trend is clear: road accident risk is elevated during adverse weather and road conditions. The national road administrations try to diminish the effects of weather conditions by maintenance operations such as ploughing, salting and gritting. However, maintenance work is often delayed and inadequate in preventing a considerable risk increment, and compensatory actions are demanded of the individual drivers as well.

Drivers are, however, not valid estimators of accident risk and do not always adjust their driving behaviour sufficiently. This is especially true concerning the road conditions in wintertime, as drivers tend to harshly underestimate the slipperiness of a road they are driving on. Slipperiness can be argued to be the most significant of weather-related risks. Furthermore, even when the road is very slippery (friction $\leqslant 0.20$), the drivers on average still drive at speeds somewhat higher than the speed limit and consider it safe (Heinijoki, 1994). Studded tires that are generally used in Nordic countries (Finland, Sweden and Norway) improve friction considerably on icy roads. However, Rumar, Berggrund, Jernberg, and Ytterbom (1976) and Summala and Merisalo (1980) showed that drivers partly trade off this effect by driving faster in curves, although still maintaining a somewhat larger safety marginal. Finally, analysis of daily winter-time crashes reveals peaks that reflect that bad weather and slippery roads surprise drivers (Anttila, Nygård, & Rämä, 2001).

It seems, then, that drivers do perceive the weather-related risks and adjust their driving behaviour accordingly to some extent, but not enough (see also Edwards, 1999). Thus, an accident prevention strategy relying on drivers' compensatory on-road driving behaviour is not likely to be successful.

Drivers can control their risks at several levels, however. It is useful to consider driver behaviour as hierarchically organized, separating tactical (and operational) on-road control and high-level strategic decision-making (Michon, 1979; Summala, 1996). The former is exemplified by compensating for the weather-related risk with adaptive driving behaviour, such as lower speeds, longer headways, and avoidance of overtaking on two-lane roads. The high-level strategic decisions include allowing more time for a trip, postponing it, choosing public transportation instead of the car, or choosing studded tires where it is allowed. However, in countries where hard winters and impaired road conditions are not unusual enough to stop daily routines, people are not free to make safe travel decisions, despite their safe intentions. Once people have learned that the road administration keeps the roads open and trafficable, they often choose the car and make the trip despite compromised road conditions. Possible exceptions are trips that are easy to postpone and certain driver groups who have more freedom of choice, such as pensioners.

It is rather obvious then, that the road administrations should do their best to help drivers control weather-related risks. In addition to maintenance work, national road administrations try to deliver information of the adverse road conditions to drivers in order to assist drivers' in their compensatory behaviour.

In Finland, the Traffic Weather Information Service (TWIS) is a service designed to produce forecasts that classify the driving conditions in a specific region as normal, poor or very poor. The service has been functioning since autumn 1997. There is a set of criteria for the different classifications and a target proportion of very poor classification. The idea is that roughly 5% of an average winter's forecasts should warn drivers of very poor driving conditions in at least some area of the country. This is, of course, subject to great variation and determined ultimately by the weather. So far, the proportion of the forecasts warning of very poor conditions has been consistently considerably lower than 5% (Anttila et al., 2001).

The Finnish National Road Administration (FINNRA) makes a weather class suggestion for the next 6 h on the basis of information gathered from automatic road weather stations, weather forecasts and maintenance operators. The Finnish Meteorological Institute then considers the predicted weather for the next 24 h and produces the traffic weather forecast for the media. The classification of a specific TWIS forecast is determined by the worst predictable conditions in a given region during the next 24 h.

The purpose of this research was to study how drivers perceive the prevailing weather and road conditions they encounter while driving and how this affects their driving behaviour. Furthermore, we studied the drivers' use of the TWIS and its possible effects on drivers' on-road driving behaviour and higher-level decision-making. Finally, the correspondence between the TWIS forecasts and the perceptions of drivers travelling in the same area at the same time was examined.

2. Methods

A questionnaire form was prepared to acquire data of the drivers' demographic variables, conditions perceptions and self-reported driver behaviour. The questionnaires included up to 44 questions, the number of questions to be answered depending partly of the drivers' answers.

The drivers were asked to rate the current driving conditions on the same three-step (normal, bad, very bad) scale that is applied in the TWIS forecasts. They were also asked to classify the slipperiness on a five-step scale from very slippery to not slippery, the weather in relation to traffic on a five-step scale from very bad to very good, and the perceived general accident risk on a five-step scale from very small to greatly elevated. The drivers were also asked whether they had acquired weather-related information for the trip. If so, they were to shortly describe the information content. They were also to report their decisions before and during the trip and to estimate their target speed, typical headways and overtaking frequency in comparison to those on the same road in good weather and driving conditions. Demographic control variables included e.g. age, gender, the type of vehicle driven and driving experience. If a driver rated the weather as bad or very bad, he was also to respond to an open question on the more specific reasons of the rating. The responses to open questions were not statistically analysed.

The questionnaire was distributed at altogether 11 service stations located along ordinary two-lane main highways outside urban areas in southern and middle areas of Finland. The data were collected between November 15, 2001 and February 27, 2002, on 16 days during which adverse conditions were expected. The drivers were asked whether they were willing to participate in a questionnaire by the University of Helsinki and the FINNRA, concerning the current driving conditions. The anonymity of the answers was addressed. Volunteering drivers were handed the questionnaire, and the distributors of questionnaires were at the drivers' disposal for additional instructions if needed. The query was returned directly after it was filled, and the exact time was coded into it. The response rate was 64%.

Altogether 1437 drivers of a passenger car, van or truck filled out the questionnaire. 82 cases were rejected due to a clearly insufficient or meaningless filling of the questionnaire.

There were 267 automatic traffic counters along highways and motorways in Finland during the research period. These measure the speed and type of each passing vehicle in one routine data compilation and report the number and average speed of each type of vehicles during a 15-min period. In this research, the traffic counter information was used as a control measure of drivers' speed reports and to observe the weather's true effects on traffic speeds. Traffic volume was also controlled when necessary, as higher traffic volume tends to lower traffic flow speeds. During the research period, at traffic counters used, the relationship between volume and speed of the measured traffic flow was approximately linear ($r = -0.293$; $p < 0.001$). This corresponds to earlier volume/speed relations on two-lane Finnish main highways (Luttinen, 2001).

Correspondingly, there were approximately 280 road weather stations (see Toivonen & Kantonen, 2001) during the research period. These measure numerous traffic related weather parameters. The parameters used in this study were air temperature, road temperature, wind speed, relative humidity, precipitation, and dew point temperature. These measures were fed into an expert system model presented and tested in Sweden by Norrman (2000). This model operates on the basis of IF–THEN rules and applies the above-mentioned

Table 1
Central sources of data and the types of information that were used in this study

Source	Type of information
Questionnaire	Drivers' conditions perceptions, forecast use and self-reported driver behaviour
Traffic Weather Information System (TWIS)	Forecasts that were in the media at the times and regions of questionnaire distribution
Traffic counters	Traffic flow volumes and average speeds for the times and regions of questionnaire distribution
Automatic road weather stations	Numerous weather-related parameters (air and road temperature, precipitation, wind speed etc.), that were fed into an expert system model
Expert system model (Norrman, 2000)	Objective estimates of driving conditions at the times and roads of questionnaire distribution

variables and classifies the prevailing road conditions either as not slippery or as one of ten types of slipperiness. This particular system was employed because no such system had been published in Finland at the time. The different slipperiness classes and their corresponding risk factors were compared to drivers' perceptions of driving conditions and accident risk. This kind of a system was considered necessary in this study because the TWIS forecasts are, in addition to road weather stations and other automatic information, based on various subjective human decisions. Thus there was a need of comparing the drivers' perceptions to a model based on objective information of road and weather parameters. The service stations used for the distribution of questionnaires were located on average 11 km from the closest automatic traffic counter on the road concerned, range 2–31 km, and 8 km from the closest road weather station, range 0–18 km.

The effect of darkness or civil twilight (sun 0–6° below horizon) was also controlled in this study. The times of sunrise and sunset and the times of civil twilight at corresponding areas were acquired from the Department of Astronomy, University of Helsinki. Finally, the TWIS forecasts concerning the times and areas of research interest were obtained. Table 1 presents the central sources of data that were used in this study and the type of data that was obtained from the sources.

3. Results

3.1. Acquisition of traffic weather information

Seventy-five percent of the drivers were driving a passenger car, 12.7% a van and 12% a truck. Approximately 20% of all drivers were on a trip shorter than 20 km. These drivers were left out of some analyses as they were considered not to have sufficient experience of the driving conditions. Eleven percent of all the participating drivers and 14% of passenger car drivers were women. This is somewhat less than would be expected according to the Finnish travel statistics. However, male drivers' journeys are longer on average (Pastinen, 1999), and thus female drivers are likely to be underrepresented on highways.

Of the participating drivers, 221 (16.4%) reported having acquired traffic related weather information for the trip in question through some medium. Of all the drivers, 13% reported having acquired information from radio, 9% from TV (the sum of these is greater than 16.4% as the drivers were allowed to answer more than one media). These portions are substantially lower compared to an earlier telephone interview research, where approximately 44% of subjects estimated having seen TWIS forecasts in TV at least once a day and 32% reported having heard them in radio that often (Anttila et al., 2001). The discrepancy is partially explained by the different nuances of the questions. The telephone interview asked if the subject had *noticed* TWIS forecasts at least once a day, the present study asked if the driver had *acquired* information for the trip in question. Some of the drivers had apparently received the information passively through e.g. the evening news, not considering it information acquisition.

To get an understanding on what type of drivers currently acquire traffic related weather information and when are they most likely to do so, acquisition of weather information (for the trip in question) was examined with a logistic regression model. Only passenger car drivers were included. The model is presented in Table 2. The drivers' characteristics that predicted information acquisition were low driving experience in kilometres

Table 2
A binary logistic regression model of the active acquisition of weather information

Variable	95% CI				
	Odds ratio	Lower	Upper	Sig.	%[a]
Age (ref. 18–20 years)				**0.00**	6
21–23	3.36	0.33	33.77	0.30	4
24–26	4.59	0.50	42.06	0.18	5
27–30	3.75	0.38	36.81	0.26	6
31–40	4.46	0.56	35.21	0.16	26
41–50	10.33	1.33	80.20	**0.03**	26
51–60	11.33	1.45	88.58	**0.02**	21
>60	33.30	4.01	276.93	**0.00**	6
Gender (ref. male)					84
Female	1.99	1.18	3.36	**0.01**	16
Thousands of km during last 12 months (ref. >50)				**0.04**	17
<5	5.50	1.64	18.48	**0.01**	4
6–10	1.73	0.67	4.42	0.26	9
11–20	2.00	0.98	4.08	0.06	25
21–35	2.10	1.06	4.17	**0.03**	29
36–50	1.11	0.53	2.33	0.78	17
Purpose of trip (ref. to/from work)				0.50	12
Work errand	1.01	0.47	2.18	0.97	27
Other errand	0.59	0.24	1.48	0.26	19
Leisure trip	1.02	0.46	2.26	0.97	42
Trip length (ref. <20 km)				**0.00**	20
20–100	3.70	1.26	10.87	**0.02**	25
>100	9.05	2.94	27.83	**0.00**	55
Frequency of the trip (ref. daily)				0.11	26
First time	1.30	0.42	3.98	0.65	4
<3 times/year	1.25	0.54	2.92	0.60	20
Monthly	0.76	0.35	1.67	0.50	30
Weekly	0.56	0.25	1.23	0.15	20
Driver's conditions rating (ref. normal or bad)					90
Very bad	2.06	1.10	3.83	**0.02**	10
Trip considered compulsory (ref. no)					43
Yes	1.14	0.73	1.76	0.57	57

Passenger car drivers only. Statistically significant findings in bold.
$n = 800$, -2 Log likelihood 637.446, Hosmer–Lemeshow (8) $\chi^2 = 9.247$, $p = 0.32$.
[a] Univariate distribution.

during the last 12 months, female sex, and old age. In addition, longer trips and conditions that were perceived as very poor were associated with increased weather information acquisition.

3.2. Drivers' perceptions of weather and road conditions

Of all the conditions ratings by drivers, 35% suggested normal, 52% poor, and 13% very poor driving conditions on the TWIS scale. It is worth noting that of all the drivers who rated the conditions normal, only 3% rated the weather in relation to traffic (on a five-step scale) good and only 20% considered the road surface to be not at all slippery. It seems that in drivers' appraisals a fair weather and a somewhat or only little slippery road surface are sufficient for driving conditions to be considered normal. This is rather understandable since most drivers in Finland are at least somewhat used to slippery roads and adverse weather in the winter.

Drivers' conditions ratings were compared with FINNRAs class suggestions and TWIS forecasts in the media. All these concern the moment the driver in question has filled out the questionnaire. Of FINNRAs suggestions, 22% indicated normal, 78% poor and 0% very poor conditions. The corresponding distribution of forecasts in the media was 2%, 68% and 30%. Of all the ratings on the three-step TWIS scale (given by drivers on a trip of 20 km or longer), 4.3% were worse, 73.4% equal, and 22.3% better than the TWIS forecast concerning the appropriate time and region. The skewness of the distribution is not very surprising as such, as the TWIS forecast is determined on the basis of the worst predictable conditions of the 24 h period on any highway in the region. The drivers' perceptions are likely to be much more local, both spatially and temporally.

To find out if there is some driver characteristics or driving conditions that especially lead to a dissociation between drivers perceptions and the forecasts, factors affecting drivers' probability to rate the conditions as better than the actual forecast were studied with a logistic regression analysis. The only significant factor was daylight. In comparison to those who participated during darkness, the drivers who participated in daylight (OR 3.965, CI 1.655–9.502) or civil twilight (3.866, 1.219–12.26) more often considered the driving conditions better than the forecast. It was further analyzed whether there is an interaction effect between conditions and light level. Indeed, both main effects of light ($F(1,916) = 19.99$, $p < 0.001$) and forecast ($F(1,916) = 81.18$, $p < 0.001$) and the interaction effect ($F(1,916) = 23.04$, $p < 0.001$) were significant in a 2×2 two-way ANOVA with drivers' conditions perceptions as a dependent variable (Fig. 1). For this analysis, the dependent variable was transformed to a binary dummy variable: the conditions were rated either very poor or not very poor. It is quite reasonable to expect that drivers evaluate the driving conditions as poorer in the dark, especially when visibility is impaired by the weather and the darkness. It can also be hypothesized that poor conditions and darkness have an interaction effect on drivers' cognitive workload and emotional strain, and thus lead to more negative perceptions of the driving conditions. Similar main and interaction effects were found with perceived risk as dependent variable (light: $F(1,956) = 17.58$, $p < 0.001$; forecast: $F(1,956) = 100.5$, $p < 0.001$, interaction: $F(1,956) = 6.625$, $p < 0.05$). There was a strong correlation between perceived adversity of conditions and perceived accident risk ($r = 0.605$, $p < 0.001$).

3.3. Effects of acquired information

The aim of traffic weather information is naturally not merely to be received, but to have an effect on driver behaviour. In this study, only 5.8% of all the drivers reported any changes in travel plans before or during the trip. However, drivers who reported active acquisition of weather information reported changes considerably more often (16.4% vs. 3.5%, $F(2,1331) = 28.4$, $p < 0.001$) than other drivers. The most frequently reported changes were allowing more time for the trip (5% of all drivers), altering the time of departure (3%) and changing the route (1%) (the sum of these is more than 5.8% because the drivers were allowed to answer more than one change).

The on-road driving behaviour of acquirers did not differ from the drivers who reported no information reception in this study. A series of 4×2 two-way ANOVAs with drivers' 5-level weather rating and acquisition vs. no reported acquisition as factors showed that the drivers' weather rating had a significant effect on speed

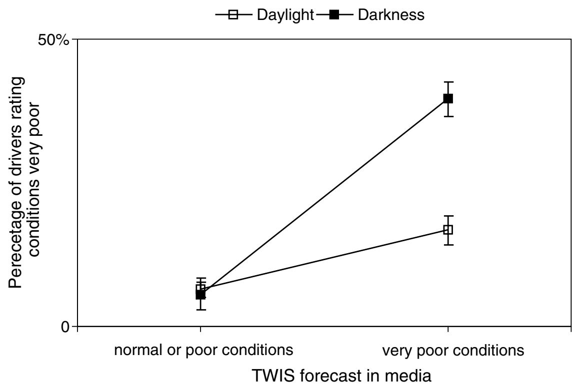

Fig. 1. Percentage of drivers considering the conditions very poor as a function of the actual TWIS forecast in the media. Drivers on a trip of at least 20 km.

choice ($F(3,1051) = 8.6$, $p < 0.01$), overtaking frequency ($F(3,1116) = 14.7$, $p < 0.001$) and headways ($F(3,1118) = 12.3$, $p < 0.001$). Information acquisition had no significant effects on speed choice: ($F(1,1051) = 0.09$, $p > 0.76$), overtaking frequency: ($F(1,1116) = 1.4$, $p > 0.23$), or headways: ($F(1,1118) = 1.5$, $p > 0.22$). There were no significant interaction effects on speed choice ($F(3,1051) = 0.5$, $p > 0.65$), overtaking frequency ($F(3,1116) = 1.4$, $p > 0.23$) or headways ($F(3,1118) = 1.0$, $p > 0.39$). The drivers' self-reported speed reductions in comparison to target speeds in normal conditions increase very similarly as a function of the 5-step weather rating (see Fig. 2). Notice that cases reporting very good weather or good weather were grouped together for these analyses as there were only 13 very good weather ratings. Hence only four groups on the weather rating factor remain in the analysis and Fig. 2.

The analysis above compared the drivers' weather condition estimates to their self-report of driving behaviour. Additional ANOVAs on self-reported driving and risk estimates were computed using objective conditions measures, i.e., light and precipitation (snowing, drawn from weather stations), as well as drivers' age group and information acquisition as classifiers, and gender, yearly driving experience, and trip length (log transformation) as covariates. Light and snowing had a clear effects on traffic flow speeds such that snowing reduced mean speed by 1.6 km/h, darkness by 2.7 km/h and both by 5.1 km/h. Correspondingly, snowing added percentage of drivers who desired to drive below 80 km/h by 1.5% units, from 4.6% to 6.1%, darkness by 6.1%-units to 10.7%, and both by 11.4%-units to 16%. Age consistently decreased reported target speed such that it was 84,8 km/h for those at age of 30 or less and 78.5 km/h for 56+ years old ones ($F(3,634) = 10{,}95$; $p < 0{,}001$). Males tended to drive faster than females ($p = 0{,}026$) and yearly mileage ($p = 0{,}008$) and trip length ($p = 0{,}003$) added to speed. However, the data did not show reliable interaction effects of the conditions and age group on target speed. Drivers' risk estimates depended, additively, both on light (darkness 3.44 vs. daylight 2.98 on 5-point scale, $F(1,651) = 21{,}02$, $p < 0{,}001$) and on snowing (yes 3.36 vs. no 3.06; $F(1,651) = 9.29$, $p = 0.002$). Additionally, information acquisition had a marked main effect on risk estimate (active acquirers 3,39 vs. no information acquisition 3.09; $F(1,651) = 5.59$, $p = 0.018$). There were no other significant main effects or interactions. Correspondingly, a similar ANOVA showed that light and snowing explained drivers' conditions ratings with highly significant main effects of light ($F(1,651) = 14.64$, $p < 0.001$) and snowing ($F(1,651) = 20.50$, $p < 0.001$).

3.4. Traffic flow speeds

To get a rough estimate on the reliability of drivers' target speed reports, and to see whether conditions have a different effect on the speed that drivers pursue and the speed they are able to maintain, questionnaire data were compared with 15-min speed averages from traffic counters. The data behave very similarly on an average level, but the correlation between them is somewhat weak ($\rho = 0.233$, $n = 681$, $p < 0.001$). This is presumably partly due to the small survey samples of each 15 min segment as well as to drivers' tendency to give

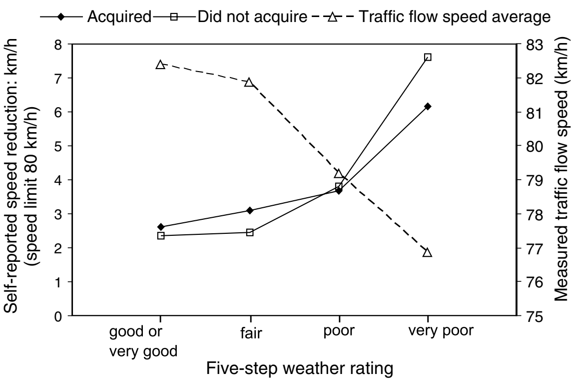

Fig. 2. Drivers' target speed reductions as a function of perceived weather conditions. Drivers on a trip of at least 20 km. The broken line shows the measured average speed of traffic flow.

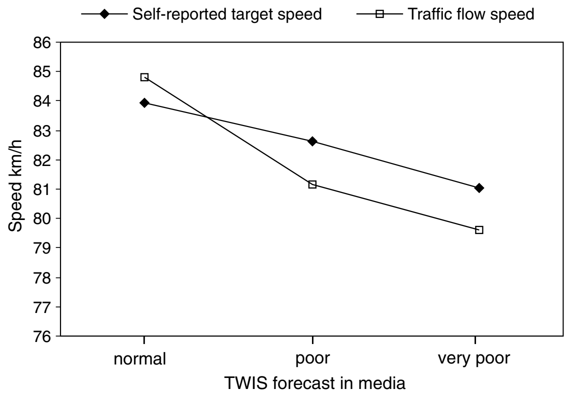

Fig. 3. Drivers' self-reported target speed averages and measured traffic flow speed averages as a function of the prevailing forecast in the media.

the speed limit as their target speed. Fig. 3 presents the two different speed measures as a function of the TWIS forecasts in the media. The traffic counter and TWIS values were matched to cases by time and region.

This study was designed to reach drivers on road in various different weather conditions in real time. Therefore, the data cannot include drivers who had decided not to drive on the particular day. In order to reach some understanding of the significance of this sort of decision-making, the acquired cases were scrutinized for possible differences in the driver populations in different weather conditions. Only drivers who participated on a weekday, were driving a passenger car, and were on a trip of 20 km or longer were included in this analysis ($n = 502$). These restrictions were necessary as work related trips are significantly underrepresented on weekends, truck drivers usually cannot and indeed do not cancel trips due to compromised weather conditions and finally, weather conditions are likely to have different effects on decisions regarding very short trips and longer ones.

Somewhat against intuition, driver populations differed only by purpose of the trip in question, not by age, gender, recent driving experience or length of the trip in question. When the forecast was very bad the driver's trip in question was more often commuting (OR 8.93, CI 2.73–29.3), a work related trip (7.94, 3.1–20.2) or an errand trip (3.78, 1.28–11.1), than a leisure trip. This result gives indirect support to the hypothesis that when the driving conditions are very poor, some of the more unnecessary trips are abandoned or postponed.

3.5. Estimates of adverse weather

Two objective measures for conditions were used in the analyses above, daylight drawn from meteorological data and precipitation (snowing) from weather station records. Slipperiness follows precipitation to some

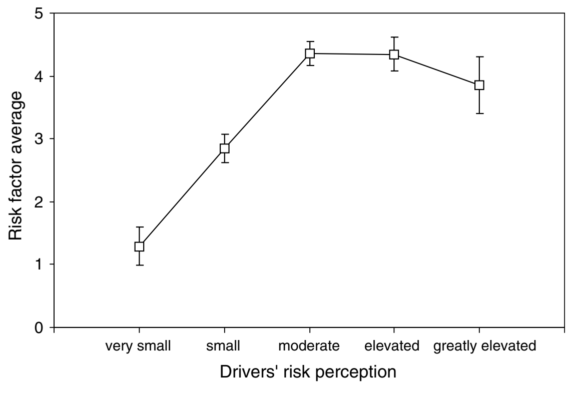

Fig. 4. Averaged risk factors (Norrman et al., 2000) as a function of drivers' risk perceptions. Passenger car drivers on a trip of 20 km or longer included.

degree but also depends on a lot of other factors. A global road condition measure is therefore quite difficult to estimate. As an attempt to compare drivers' perceptions to a more objective than the TWIS forecasts, an expert system was used. The cases were compared to the prevailing slipperiness classes and their accident risk according to Norrman, Eriksson, and Lindqvist (2000). Some limitations must be pointed out. First, the accident risk analyses of Norrman et al. (2000) are based on a rather small sample of accidents ($n = 246$). Secondly, the maritime climate of Götaland (in Southwest-Sweden) differs considerably from the more continental climate of the locations of the present study (in Finland).

A series of one-way ANOVAs showed that the slipperiness type had a significant effect on all driver perceptions, including drivers' ratings of conditions on the three-step TWIS scale ($F(8,945) = 10.04$, $p < 0.001$), perceived slipperiness of the road in question ($F(8,948) = 10.5$, $p < 0.001$), five-step weather rating ($F(8,945) = 16.53$, $p < 0.001$), and perceived accident risk ($F(8,949) = 5.45$, $p < 0.001$).

When drivers' perceived accident risk is compared to the corresponding slipperiness risk prevailing on the same road at the moment of driver participation, the result is quite consistent. The risk factor averages are presented as a function of drivers' perceptions in Fig. 4. Only passenger car drivers on a trip of 20 km or longer are included. The risk factor averages according to Norrman et al. (2000) are significantly greater when the drivers perceive elevated accident risks, although the ceiling is reached already at moderate risk level.

The comparisons between slipperiness types should be considered highly preliminary due to a small number of observations, especially among some slipperiness types. Maintenance operations may also have a substantial effect on drivers' subjective perceptions. It is intuitively quite understandable that Finnish drivers do not consider hoar frost or snowing on a warm road surface as very risky wintertime conditions.

4. Discussion

To have an effect on traffic safety, a traffic weather information system should be easily accessible to drivers, used by a considerable proportion of them, appear reliable and, finally, contribute to pre-trip decisions and on-road driving. In this study, active acquisition of weather information was reported by one out of six participating drivers who had decided to take a trip. Those who did report active information acquisition also reported significantly more strategic changes in their travel decisions. However, no effects of information acquisition on the low-level driving behaviour, such as target speed, headway, or overtaking frequency, were found.

Information acquisition was predicted by a number of driver characteristics. The effects of higher age can be understood in light of the fact that older drivers generally tend to avoid difficult driving conditions due to decreasing cognitive performance (Ball et al., 1998; Raitanen, Törmäkangas, Mollenkopf, & Marcellini, 2003; Parker, MacDonald, Sutcliffe, & Rabbitt, 2001; Rimmö & Hakamies-Blomqvist, 2002; Schlag, 1993) while those already on pension are also better able to postpone or abandon their trips. Younger drivers, especially male, tend to overestimate their own driving abilities and underestimate the risks of various traffic situations (Dejoy, 1992; Matthews & Moran, 1986). This may lower their motivation to search for information on driving conditions. Low recent driving experience and length of the trip in question are also intuitively quite understandable factors. The result that those drivers who considered the conditions very bad also reported more information acquisition probably comes from many sources. It is plausible that drivers are more likely to remember and report TWIS forecasts when weather conditions are indeed compromised. These incidences are more uncommon and significant than normal weather conditions. Another possible contributor is that drivers are more likely to acquire forecast information if the observable weather is adverse or deteriorating during the time before the trip. It can also be assumed that people who generally worry about safety both actively use weather information and evaluate conditions worse (e.g. Matthews, Dorn, & Glendon, 1991). This explanation is supported by the result that those who acquired information gave higher risk estimates even when trip and person-centred factors were controlled.

Drivers' conditions ratings did not correspond very well to the traffic weather forecasts. The two different time spans behind a forecast and a driver's rating can partially account for these low correlations. In addition, the drivers' perceptions are most likely to concern a specific road, while the forecast classifies a whole region on the basis of the worst conditions inside the region. Local maintenance operations can also have temporary and unpredictable effects on drivers' perceptions. In the open questions of this study, the drivers mentioned salting quite often as a negative phenomenon that hinders visibility.

One driver-related source of disagreement between the forecasts and perceptions appears to be ambient light level. Drivers generally tended to consider the conditions better than the forecast, more so during daylight and civil twilight, than during darkness. The difference between conditions perceptions during daylight and darkness was clearly greater when the TWIS forecast indicated very poor conditions.

At first sight, daylight should facilitate drivers' perceptions of compromised road conditions and thus make condition estimates more valid, contrary to the present finding. On the other hand, the different time spans and area extents behind the estimates and forecasts make the disagreement quite understandable. Thus, it is more puzzling that darkness brings the two measures more into agreement. However, we may assume that drivers relate conditions ratings to how well they manage with the conditions, i.e., to their feeling of control (Summala, 1988) or task capability (Fuller, 2005). With increasing experience of winter conditions, they presumably overestimate their task control and underestimate condition severity. Such ''risk adaptation'' is predicted both by the zero-risk theory (Näätänen & Summala, 1976; Summala, 1988) and task-capability theory (Fuller, 2005). Darkness, however, makes drivers' task more difficult, especially in bad weather, when darkness hinders perception of road delineation and pavement condition and reduces preview distance and time. Correspondingly, roadside reflector posts (Kallberg, 1993), road lighting (Assum, Björnskau, Fosser, & Sagberg, 1999) and edge lines (Steyvers & de Waard, 2000) increase driving speeds in darkness. Snowing as such predicts pavement slipperiness while the combination of snowing and darkness effectively reduces preview and available time margins and, consequently, driving is felt loading and stressful (Summala, 1997, 2005). This presumably shifts conditions ratings closer to the forecasts in the dark. The present data indeed showed that precipitation (snow or sleet) and darkness additively reduced traffic flow speeds and drivers' conditions ratings and increased their risk estimates.

The drivers' perceptions of driving conditions were in fair accordance with the automatic expert systems classifications and their risk factors. The results are not consistent, but they certainly encourage further research. The slipperiness classifications yielded by expert systems such as that of Norrman (2000) should be applied to more extensive and spatially representative road weather station data and be compared to corresponding accident data.

It is plausible that forecasts can help drivers to make some safety related trip decisions. This research indicates that people who had actively acquired weather-related information for their trip also made significantly more deliberate trip-related decisions before or during the trip. However, acquisition of weather forecast information from TWIS had no effect on on-road driving behaviour. This finding is in line with the results of Hanscom (1976) and Rämä and Kulmala (2000), who studied the effects of traffic signs warning of slipperiness, when appropriate. In their data, the decrement effects on driving speeds in both studies were quite modest, approximately 1–2 km/h. In addition, Rämä and Kulmala found no effects on headways. A traffic sign cautioning of slipperiness is a rather concrete and local warning. Yet, the above-mentioned effects can be considered quite inadequate. The effects on speeds were somewhat greater (3–6 km/h) in a similar study with a specific speed limit displayed during slipperiness (Rämä, 1999). This is possibly due to speed limits' more unambiguous, regulatory and sanction entailing nature. On the basis of Hanscom (1976), Rämä (1999), and Rämä and Kulmala (2000), it can be argued that a concrete and commanding traffic sign has a greater effect on driving behaviour than more generally informing signs, let alone a spatially and temporally diffuse weather forecast. This is well in line with early research on conventional traffic signs (Johansson & Backlund, 1970; Johansson & Rumar, 1966; Summala & Hietamäki, 1984).

At first sight, there seems to be a discrepancy between the forecasts' effect on the high-level decision-making and lack of effect on the on-road driving behaviour. However, a simple and parsimonious way to explain this discrepancy is the drivers' use of information that is easily available and perceived as the most reliable. Before a long trip the most available and reliable information on the weather conditions along the route are the forecasts. En route, however, the driver's own direct observations of the conditions are the most available and probably perceived (usually correctly) as the most reliable.

A shortcoming of this study was that no objective individual speed measurements were available. However, the self-reported target speeds correspond very well to the simultaneous traffic flow speed averages (see Fig. 2).

Also, it is quite likely that somewhat different driver populations have been reached during different conditions. This study provided indirect evidence that drivers on a leisure trip were underrepresented during very poor conditions. Differences between the populations who travel and those that do not travel or choose transit during adverse weather conditions should be more directly studied in further research. Also, weather information's role in these choices would be interesting to determine.

The results of this study have implications to those who aim to reduce accidents in adverse weather conditions. To diminish the accident rate among those drivers who cannot or do not wish to postpone the trip, the measures should be more concrete, local and technical than the TWIS. At the least, the weather information should be updated more frequently. An example of local and temporally accurate warnings is a precise and standardized variable message system that displays concrete driving behaviour instructions for example current speed limit or overtaking restrictions (Luoma, Rämä, Penttinen, & Anttila, 2000; Rämä, 1999; Rämä & Kulmala, 2000; Wang & Cao, 2003). Mobile in-vehicle information technology is now increasingly providing effective means of distributing local real-time road information. The automobile industry is also actively developing instruments into vehicles to measure relevant safety related parameters, especially friction (e.g. Gustafsson, 1997; Ogura et al., 2002). Such information can further be applied to intelligent speed adaptation systems (e.g. Varhelyi, 2002) and real-time fleet data collection (e.g. Pilli-Sihvola, 2001).

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