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Chosen risk level during car-following in adverse weather conditions

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ABSTRACT

This study examines how precipitation, light conditions and surface conditions affect the drivers' risk perception. An indicator CRI (Chosen Risk Index) is defined, which describes the chosen risk level for drivers in a car-following situation. The dataset contains about 70 000 observations of driver behaviour and weather status on a rural road. Based on the theory of risk homeostasis and an assumption that driving behaviour in situations with daylight, dry road and no precipitation reflects drivers' target level of risk, generalised linear models (GLM) were estimated for cars and trucks separately to reveal the effect of adverse weather conditions on risk perception. The analyses show that both car and truck drivers perceive the highest risk when driving on snow covered roads. For car drivers, a snow covered road in combination with moderate rain or light snow are the factors which lowers the CRI the most. For trucks, snow cover and partially covered roads significantly lowers the CRI, while precipitation did not seem to impose any higher risk. Interaction effects were found for car drivers only.

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1. Introduction

The challenges of driving vary according to varying driving conditions. Among these are changes in weather and road conditions. Rain, snow and ice alter the friction between the tires and the road surface, while precipitation may impair the driver's visual ability to detect potential dangers, as do driving in twilight and dark hours. How do drivers perceive and respond to risk under such varying conditions?

1.1. Theoretical approach

Numerous theories and models have been developed to better understand and predict road user behaviour. Risk perception is a central component and predictor in many of these, proposing that road users' perceptions of risk influence their behavioural choices. One of these theories is Wilde's Risk homeostasis theory (Wilde, 1982) in which he suggests that individuals continuously compare their perceived level of risk to their target level of risk and take behavioural decisions in order to balance the two. The target level of risk represents the levels of risk individual drivers are willing to take. In order to maintain the balance between perceived and target risk, the theory posits that if drivers perceive an increased risk, for example due to reduced friction, they will adjust their driving accordingly to reduce the risk they are facing. In a situation with perceived reduced friction, lowering speed or increasing the time gap could be possible strategies to avoid exceeding the desired target level of risk. The theory has, however, been mostly used to advocate that traffic safety measures have no effect since a lowered perceived risk level will be met by a more risky behaviour. Thus, a reduction in traffic accidents will only take place if the target level of risk is lowered.

Wilde's theory has been heavily discussed and criticised, and is regarded more as an interesting basis for discussion by identifying important mechanisms in human behaviour, than as an applicable model. Since it is not possible to falsify the theory, it has no explanatory value (Elvik et al., 2009). However, the notion of drivers adjusting their behaviour as a response to changes in their environment is the basis for the concept of behavioural adaptation (OECD, 1990). The concept behavioural adaptation was redefined by Kulmala and Rämä (2013) as "Any change of driver, traveller, and travel behaviours that occurs following user interaction with a change to the road traffic system, in addition to those behaviours specifically and immediately targeted by the initiators of the change". Although this concept is mostly discussed as a response to implemented measures, it is also meaningful to apply when discussing driver behaviour as a response to natural changes in weather and road surface conditions. These are changes that are easily observed and therefore likely to evoke changes in risk perception, which in turn may affect the behavioural decisions taken by the drivers.

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Van der Molen and Bötticher (1988) suggested a hierarchical risk model in which drivers' tasks take place at three levels: strategical, tactical and operational. Decisions about choice of speed and time gap belong at both strategical and tactical level. At strategical level, strategies for the journey are planned, such as general strategies for choice of speed and time gap, depending on weather and road surface conditions. At tactical level, however, these strategies are transformed into manoeuvring plans with short time spans based on the current situation. These manoeuvring plans are put into action at operational level. At both strategical and tactical level, drivers perceive information from their environments and make judgements based on their motivations and expectations. The model utilises utility functions in the decision process, in which both risk and other judgements are included. These judgements and the decision rules may vary both intra- and inter-individually. Both Wilde's risk homeostasis theory and the concept of behavioural adaptation can be integrated into this model. In both cases, risk perception is a key element. Slovic and Peters (2006) claim that risk can be perceived in two ways, both analytical and as feelings. Risk as feelings is the most intuitive way of perceiving risk while the analytical way is based on logic and reason. Risk perception at strategical level is suggested to be more analytical than risk perception at tactical level. Thus, there is a mixture of both analytical and emotional elements to risk perception when driving at adverse conditions.

1.2. State of research

Several studies have investigated how driving behaviour is affected by adverse conditions, and how the accident rates change as well. The following statements can be made based on the literature:

1.2.1. Precipitation reduces speed and increases time gap, and the speed reduction is larger for higher intensities

Rain and snow disturbs the field of view enough to influence the traffic flow. This is shown empirically by several studies. Agarwal et al. (2005) found that speed was reduced by rain and snow, and that the reduction was dependent on the precipitation intensity. In heavy rain and heavy snow the speed was reduced by respectively 4%–7% and 11%–15%. A study by Billot et al. (2009) also found that drivers reduce their speed during rain, and the impact was increasing with precipitation intensity. Rahman and Lownes (2012) found that a shift from no-rain to rain led to a speed reduction of 3.7% and an increase in time gap of 5.7%. Lam et al. (2013) studied the impact of rain intensity on the Hong Kong road network, and found that speed decrease as the rain intensity increases.

1.2.2. Precipitation increases accident rate

During rain or snow, changing driving conditions leads to more accidents. Eisenberg and Warner (2005) found that snowy days have fewer fatal accidents, but more nonfatal injury accidents. A study by Hermans et al. (2006) showed that among several weather indicators, the presence of precipitation had the most significant impact on number of accidents. Qiu and Nixon (2008) conducted a meta study of 34 papers and 78 records showed an increase in accident rate during precipitation. Snow had the greatest effect, with a possible increase in accident rate by 84% and injury rate by 75%. Karlaftis and Yannis (2010) found a surprising decrease in accident rate for increasing precipitation intensity, and suggested that a decrease in speed as well as Southern European drivers being unaccustomed to wet roads as an explanation. Strong et al. (2010) reported that snowy weather leads to a decrease in speed and an increase in accident frequency, but a decreased number of fatal accidents. They attributed this primarily to the fact that the severity of accidents decrease as the speed decreases. Mills et al. (2011) found that precipitation in the form of both rain and snow substantially increases the risk of injury collision. Andrey et al. (2013) performed a risk analysis showing an increase in collision rate on days with snow, and a higher relative risk in rural areas than in urban areas. Bergel-Hayat et al. (2013) studied a large European dataset of weather and injury reports, and found significant correlations between weather and accident rate, but the results varied for different road types. On motorways, the effect of rainfall was direct, but on main roads, the effect was indirect through exposure.

1.2.3. Water, snow or ice on the road surface reduce speed and increase time gap

Typical values of coefficients of friction are: dry surface (0.80–1.00), wet surface (0.40–0.90), snow covered surface (0.15–0.30), and ice covered surface (0.05–0.15) (Aurstad et al., 2011). The reduced friction, either from rain, snow or ice will lead to longer braking distances and reduced handling capabilities. Strong et al. (2010) summarised the results from earlier studies on how weather affects speed and accident rate in an extensive literature review, showing how the speed reduces with increasing adversity for pavement conditions. In the worst case, which was "very icy", the speed adjustment factor was estimated to be 0.83. Dixit et al. (2012) reported that drivers behave more careful in situations with a wet road surface compared to situations with a dry surface. Kwon et al. (2013) found that road surface condition has a significant effect on free flow speed and capacity. They calibrated models based on empirical data which estimated a reduction of 17.0% in free flow speed for a snow covered road, and an 11.0% reduction for wet road surface. Kvernland (2013) observed speed at several places along a straight road section ending in a curve during winter conditions. Compared to dry surface, he found speed reductions of 5.9–13.9% on icy surface and 4.6–12.2% on snow covered surface, but hardly any changes on wet surface. The highest reductions were found just before entering the curve. However, calculations based on measured friction showed that none of these speed reductions were sufficient to fully compensate for the reduced friction.

1.2.4. Water, snow or ice on the road surface increases accident rate

The challenging driving conditions during reduced friction often lead to a loss of control of the vehicle. Keay and Simmonds (2006) investigated the impact of rainfall on daily road accidents in Australia and found that the risk is greater in wet conditions caused by rainfall. Strong et al. (2010) also found that the accident rate increased with more adverse surface conditions. In the worst condition, "very icy", their accident adjusted factor was 1600% as opposed to 100% for dry roads. A meta study by Elvik et al. (2009) derives relative accident risks for adverse lighting and surface conditions based on Norwegian studies. They found that the relative risk increased to 1.3 for wet surfaces, 1.5 for slushy roads and 2.5 for icy or snow covered surfaces.

1.2.5. Lower visibility reduces speed and increases time gap

Another important factor is the reduced sight caused by precipitation, somewhat depending of the time of day. When driving in daylight during a dry spell, the sight is usually quite good, and eventual hazards can be spotted in time for the driver to react. On the other hand, driving in heavy snowfall or fog at night will dramatically reduce the visibility. During situations of reduced sight, the ability of the driver to detect potential hazards will decrease. Hoogendoorn et al. (2010) showed that fog leads to a significant reduction in speed and a significant increase in gap. The study by Kwon et al. (2013) found that visibility, measured in sight distance, has a significant effect on free flow speed and capacity, showing an increase in speed and capacity for increasing visibility.

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